SORGHUM MIDGE, *Contarinia sorghicola* (COQUILLETT) (DIPTERA: CECIDOMYIIDAE), BIONOMICS AND POPULATION RESPONSE TO MANAGEMENT TACTICS

BY

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SORGHUM MIDGE, Contarinia sorghicola (COQUILLETT)
(DIPTERA:CECIDOMYIIDAE), BIONOMICS AND
POPULATION RESPONSE TO MANAGEMENT TACTICS

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Bionomics and behavior of the sorghum midge, Contarinia sorghicola (Coquillett), pertinent to controlling the midge were studied. These included manner of the midge dispersal and time of sorghum field invasion, infestation pattern of the midge for oviposition in the top, middle, and bottom parts of the sorghum head, temporal emergence pattern of the midge from infested sorghum head, stages of the sorghum head susceptible to the midge after exertion from the boot, and population dynamics of the midge in sorghum. Effects of sorghum planting dates, insecticides, sorghum hybrids, and no-tillage method of grain sorghum production on infestation level of the sorghum midge were also determined.

The purpose of the study was to obtain knowledge about the sorghum midge and the effects of those factors that could influence midge populations in sorghum.

The methodology consisted of sticky traps, sorghum midge emergence cages, and visual rating. Experimental layouts comprised appropriate statistical designs, e.g., a randomized complete block and latin square

split plot. Duncan's multiple range test was used to determine significant differences among means whenever necessary.

Sorghum midge dispersal depended on the prevailing wind, and sorghum field invasion on the time of sorghum head emergence from the boot. Day 2 after sorghum head emergence from the boot was the earliest time sorghum became susceptible to the midge, with infestation peaking 4-7 days after head emergence. The top, middle, and bottom positions of the sorghum head had no influence on oviposition. Emergence of adult midges from sorghum heads was more frequent in the morning hours (4:00 a.m.-11:00 a.m.) than in the afternoon or at night.

Midge population was low early in the growing season but reached high levels and peaked toward the end of the growing season due to extensive breeding sites provided by continuously flowering sorghum in the field and overlapping generations.

Early planting (March/April) of sorghum was better than late (June/July) planting. Sorghum planted early suffered a grain loss of only 0.8-7.8% while a loss of 38.0-94.0% was sustained by sorghum planted late. Yield in sorghum planted early was also higher.

Diazinon, methyl parathion, dimilin, FMC 33297, and carbaryl evaluated against the sorghum midge, did not show significant difference in performance on yield or midge populations. However, all had potential for midge control.

Data gathered to determine susceptibility of grain and silage sorghum hybrids to the sorghum midge indicated that of the 52 grain sorghum hybrids examined, three were consistently susceptible throughout Florida, and four were less susceptible. The susceptible group

consisted of Young (Surgro) (FMC) Early Oro, ACCO D-2912(ex-0912), and DeKalb BR-64. The less susceptible group consisted of Pioneer 8311, TE(Golden Acres) Hondo, DeKalb D-46, and Ring Around 808GB. The other 45 grain sorghum hybrids were mid-range in their response to the sorghum midge.

The silage sorghum hybrids were more susceptible to the sorghum midge throughout Florida than the grain sorghum hybrids. Average percent grain loss/head was 15.7% versus 1.0%, respectively.

Grain sorghum planted in lupin mulch and lupin stubble no-tillage plots performed better than sorghum planted in rye mulch or rye stubble and conventional tillage plots. In the former tillage types, sorghum flowered earlier, escaped midge damage more successfully and produced higher yields than in the latter tillage types.

The study has attempted to provide information useful for manipulating the sorghum midge population; it has also tried to furnish an overview of the effects of those factors that could influence midge numbers in the area. However, further research is recommended, particularly in the area of sorghum varieties and no-tillage production of grain sorghum.

CHAPTER I

INTRODUCTION

Grain sorghum, Sorghum bicolor (L) Moench, is a crop of great versatility and considerable potential in the world, being utilized as a main food and a feed for livestock. It is mainly grown in the tropics and subtropics, but also cultivated to some extent in a few temperate areas. As a world food grain sorghum is probably exceeded in importance only by wheat and rice. In Africa and Asia, it ranks with corn and rice as a major food crop, and in the USA, where about 50% of the world's grain sorghum is produced, it is grown for forage and silage as well as for a grain crop.

The three leading states in grain sorghum production in the USA are Texas, Kansas, and Nebraska, each of which produces an estimated annual average of 7.2, 4.2, and 2.9 million metric tons of grain from 3.0, 1.9, and 0.9 million ha, respectively (Anonymous, 1977). Florida, though suitable for grain sorghum production because of its tropical and subtropical climate and soil, has a relatively negligible acreage and production. In 1973, the total acreage planted with grain sorghum was ca 8,097 ha and production was ca 0.02 million metric tons (Anonymous, 1975a). Eighteen sorghum varieties (8 bird resistant and 10 non-bird resistant) were recommended to farmers then, based on yield performance after the grain sorghum hybrids were tested for 2 years (Anonymous, 1973). In 1977, grain sorghum acreage reportedly increased to about 10,240 ha in 35 counties most of which were in north-east and north-west

Florida (Figure 1). Sixteen counties planted more than 200 ha each. In 1976 and 1977, 52 sorghum hybrids were grown in tests state-wide under State Project FLA-AY-01590 for yield performance (Anonymous, 1978). The best yielding varieties may soon be released to farmers in addition to the 18 varieties mentioned earlier. More acreage is expected to be planted with sorghum in the future and therefore more emphasis on new sorghum varieties is anticipated. Thus, from this brief account it can be concluded that sorghum varieties and production acreage in Florida are increasing annually.

Grain sorghum is subject to attack by numerous insect pests. Many workers, the latest Young and Teetes (1977), agree that of all the grain sorghum insect pests the most important is probably the sorghum midge. The midge has been observed in several locations in Florida (Figure 1), and the threat it poses is imminent in view of expanded sorghum acreage and introduction of new sorghum varieties.

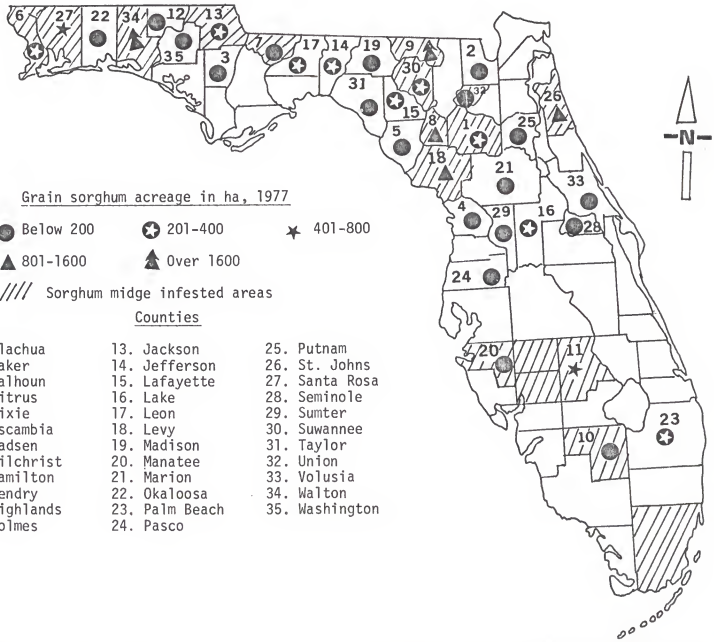
Notably, Passlow (1960) in Queensland, Australia, reported that the sorghum midge was not of economic importance when first recorded by Tryon (1894), but it became an economic pest as a result of a considerable expansion in the acreage sown for grain production. Wiseman and McMillian (1968) in Tifton, Georgia, pointed out the possibility that increasing sorghum acreage required that more attention be paid to the sorghum midge. Pradhan (1969) in India explained that increases in the intensity of cropping and the growing of high yielding varieties had contributed to the increase in loss of yield due to attack by midge. Bottrell (1971) remarked that intensified insect problems paralleled increased grain sorghum production in Texas during the 1960's.

Therefore, if expansion in acreage and varieties contributes to insect conditions, it follows that, as a result of these practices, Florida's sorghum could be predisposed to severe sorghum midge infestation. There is, however, a paucity of data concerning the sorghum midge in Florida. Moreover, since grain sorghum is increasingly important in the economy and offers potential for added amounts of feed and forage, the need for data of the key pest species becomes paramount.

Hence, a study was initiated to determine: (1) bionomics and population dynamics of the sorghum midge on sorghum, (2) influence of dates of sorghum planting and effects of insecticides on the populations of the sorghum midge and sorghum yield, (3) effects of sorghum varieties on levels of grain sorghum infestation and damage, and (4) impact of several tillage operations and nitrogen fertilizer levels on sorghum midge infestation and grain damage.

Experimental work was done at Quincy, Florida, and at Gainesville, Florida. Data on cultivar susceptibility were obtained from several areas of the State. It is hoped that the data presented here will contribute to knowledge of sorghum midge and provide a foundation for further investigation of the pest in Florida.

Figure 1. Grain sorghum acreage by county and sorghum midge areas in Florida, 1977. Source: Agricultural Stabilization and Conservation Service, and Department of Plant Industry, Gainesville, Florida.



Counties

1. Alachua
2. Baker
3. Calhoun
4. Citrus
5. Dixie
6. Escambia
7. Gadsen
8. Gilchrist
9. Hamilton
10. Hendry
11. Highlands
12. Holmes
13. Jackson
14. Jefferson
15. Lafayette
16. Lake
17. Leon
18. Levy
19. Madison
20. Manatee
21. Marion
22. Okaloosa
23. Palm Beach
24. Pasco
25. Putnam
26. St. Johns
27. Santa Rosa
28. Seminole
29. Sumter
30. Suwannee
31. Taylor
32. Union
33. Volusia
34. Walton
35. Washington

CHAPTER 2

LITERATURE REVIEW

History of the Sorghum Midge in USA

The earliest reference to the sorghum midge described the appearance of several heads of sweet sorghum received from Dillburg and Montgomery, Alabama (Coquillett, 1989). The sorghum heads contained a large number of spikelets which failed to mature seeds and which had apparently been destroyed by a cecidomyiid larva. Empty pupal skins attached to the spikelets of the damaged seed gave no clue to the identity of the species (Walter, 1941). Later in the year 1898, Coquillett received several heads of sorghum from College Station, Texas, and these contained specimens of the midge. The cecidomyiid pest, determined as a new species, was described and named Diplosidis sorghicola (Walter, 1941).

Ball (1908) reported that the same insect was responsible for sorghum seed sterility in Texas and Louisiana. Ball briefly described the life history, and proposed the common name "sorghum midge." Additional observations and suggestions for means of control of the sorghum midge soon followed (Herrick, 1909; Dean, 1911; Ball and Hastings, 1912; Newell, 1915).

A cooperative research project among the different agents of the United States Department of Agriculture in Louisiana was initiated to determine the bionomics and life history of the new pest (Walter, 1941).

Short reports of this project were published (Dean, 1910, 1911) and later Gable et al. (1928) published work that described practical methods to control the sorghum midge. However, the question of the midge's origin remained unresolved. It was believed to have originated from southern Asia (India) because of great similarity in life history of the sorghum midge to that of its counterpart, Contarinia caudata Felt, an endemic species to India (Walter, 1941). But Harris (1964) agreeing with Barnes (1956) was of the opinion that the sorghum midge had originated from Sudan in Africa. They reasoned that since the midge was present in the Sudan in 1869, 26 years before it was discovered in the USA, and since the midge was in association with Sorghum vulgare whose origin is Africa, it therefore could have been introduced into America from Africa. By dissecting midge pupae out of old herbarium specimens of the genus Sorghum, Harris (1964) produced evidence to support their interpretation which later confirmed that Barnes' (1956) assumption was probable.

Description and Life History

The sorghum midge is a cosmopolitan insect pest of grain sorghum. It has been described and its life history studied by many workers including Dean (1911), Walter (1941), Harris (1961), Bowden (1965) and Harding (1965b)

The Adult

Adults of the sorghum midge are minute, orange colored, 2-winged cecidomyiids of the Order Diptera. The male measures approximately 1.3 mm in length and the female, 1.6. The sexes are differentiated by the more robust appearance of the female and by the length of the

antennae (Figure 19). The antennae of the male are nearly as long as the body whereas those of the female are less than half the length of the body (Walter, 1941).

Mating and Oviposition

The female normally mates once in her lifetime, soon after emergence from and before leaving the host spikelet (Dean, 1911; Walter, 1941; Harris, 1961). A premating period of ca 30-80 minutes has been reported (Gowda, 1975). The mated female flies to the nearest suitable sorghum head and begins to oviposit. During oviposition, the female maintains a continuous agitated exploration of the spikelet with her long ovipositor (Figures 17 and 18). The ovipositor is inserted between the glumes which become slightly parted by the emergence of the anthers during anthesis. Eggs are thus laid within the spikelet. Although feeble fliers, females hold on to favorable heads quite remarkably despite strong winds (Harris, 1961). Oviposition may continue for as long as the glumes remain flexible, probably from 5 to 7 days (Dean, 1911; Barral et al., 1974). Many eggs may be laid in a spikelet but it is doubtful if all are deposited by one female (Walter, 1941; Harris, 1961; Taley et al., 1972; Barral et al., 1974). Normally, one larva develops to maturity in each spikelet, but 2-3 pupae per spikelet have been observed (Bowden, 1965).

The Egg

Dean (1911) and Walter (1941) described appearance of the egg of the sorghum midge as cylindrical, yellowish pink, very delicate and smaller at one end. A slender tapering appendage is attached to the small end. Walter (1941) believes that the appendage is used to anchor the egg to the glume as the ovipositor is pulled away. The dimensions

of a freshly deposited egg are ca 0.3 mm long and 0.1 mm wide (Walter, 1941).

Location of the egg within a spikelet varies in accordance with the stage of development of the glume. But generally, the eggs are found near the apex of the ovary, located in practically every part of the inner seed structure. Incubation of the egg varies with temperature and possibly other factors, and may range from 2-3 days (Walter, 1941). Harris (1961) found the incubation period to be 4 days. Taley et al. (1972) reported about 4 days. Gowda (1975) reported about 3 days and Rao (1976), 1-2 days.

The Larva

The newly hatched larva (1st instar) closely resembles the egg in shape and appearance, and is pale yellow (Dean, 1911; Walter, 1941). After hatching, the larva crawls down toward the base of the spikelet, feeds by sucking the juice of the developing seed and gradually becomes reddish orange. The shape flattens and the larva tapers to a point at the head (Walter, 1941).

The mature larva is ca 0.8 mm wide and 2.1 mm long. Just before pupation, it ceases feeding and remains quiet. During this time, the orange color disappears near the head and the larva reverses itself in the depression of the damaged seed; turning the head toward the apex of the spikelet. It then pupates and remains there until ready to emerge as adult. The time spent as larva varies according to environmental conditions, but the range in summer is from 9-11 days (Walter, 1941). Taley et al. (1972) reported about 11 days with four larval instars. Gowda (1975) reported ca 10 days with four larval instars also, but Rao (1976) found a range of 7-12 days.

The majority of the larvae form normal naked pupae on completion of growth, but a varying proportion, depending on temperature, form cocoons at the place where they have been feeding. They enter resting periods which may last 2-3 years (Coutin, 1970). The cocoons vary considerably in size depending on size and condition of the larva at the time it is formed. The cocooned larva is a resting stage which is an adaptation for carrying the species over periods of adversity. Many workers including Cowland (1936) in the Sudan, Geering (1953) in East Africa (Uganda), Passlow (1954) in Queensland, Australia, Harris (1961) in Nigeria, Bowden (1965) in Ghana, and Harding (1965b) in Texas (USA) have reported the cocooned larva.

The Pupa

When newly formed, the pupa is uniformally dark orange, but after a few hours the head, antennae, legs and thorax darken until they become black while the abdomen retains the orange color (Dean, 1911; Walter, 1941). Duration of the pupal period, for the pupae derived from normal larvae in summer, is 5-6 days. Gowda (1975) found ca 7 days, and Rao (1976) reported 3-5 days. Pupae from cocooned larvae may live a slightly longer period (Walter, 1941; Harris, 1961). The pupa is incapable of withstanding a long period of either drought or cold weather hence it is not capable of carrying the species through periods of adversity.

The Adult Emergence

When the adult sorghum midge is ready to emerge, the pupa works its way toward the apex of the spikelet until about three-fourths of the body protrudes from the tip. The pupal skin then separates from the adult by splitting along the dorsum of the thorax (Walter, 1941). The

head of the adult is gradually thrust out through the opening and then finally the entire body, being assisted by the legs. The pupal skin remains protruding from the tip of the spikelet (Figure 20).

When undisturbed, the adult usually remains quiet for at least 15 minutes or until the wings have expanded and hardened. However, when disturbed, the adult sometimes attempts to fly away immediately after emergence (Walter, 1941).

Adult emergence may occur at any time of the day but is more frequent at about sunrise or soon after. Over 60% of the total emergence takes place between 5:00 a.m. and 8:00 a.m. (Dean, 1911; Walter, 1941; Harris, 1961; Bowden, 1965; Harding, 1965b; Summers, 1975).

Adults of the sorghum midge are not known to feed and live for a very short time (Dean, 1911; Walter, 1941, 1953). The male lives for a few hours and the female for about 24-48 hours (Rao, 1976) dying soon after oviposition. Number of eggs laid per female ranges from 50-90 (Harris, 1961; Bowden, 1965) or from 50-250 eggs (Thomas and Cate, Jr., 1971). Gowda (1975) and Rao (1976) reported an average of 31.1 and 48.5 eggs/female, respectively.

Duration of Life Cycle and Numbers of Generations per Year

The duration in which the life cycle of the midge is completed varies according to environmental factors. A range in summer of 12-25 days was reported by Dean (1911), Ball and Hastings (1912), Walter (1941), Geering (1953), Passlow (1955, 1965), Matthee and Oberholzer (1958), Harris (1961), Doering and Randolph (1963), Montoya and Randolph (1964), Bowden (1965), Taley et al. (1972), Barral et al. (1974), and Rao (1976).

The number of generation per year varies with the season also. A range of 9-13 generations per year has been reported by Walter (1941), Matthee and Oberholzer (1958), Harris (1961), and Passlow (1965). Normally, adults of the first generation start to emerge from cocooned larvae in late March or early April and halt in November or December when host plants become unavailable (Walter, 1941).

Damage Symptoms and Economic Infestation

Damage Symptoms

The damage symptoms on the sorghum are those shown by the crop itself and which are inflicted upon it by the larvae. Feeding on the juices of the developing seed causes them to dry up and become discolored. The infested grain heads appear blighted or blasted (Figure 2). An infestation of one larva per spikelet is sufficient to cause the loss of the grain (Walter, 1953; Harris, 1969).

Economic Infestation

Young and Teetes (1977) and early workers reported that the sorghum midge probably is the most important of all the sorghum insect pests. Losses in grain production caused by the sorghum midge are estimated at millions of dollars each year.

In San Antonio, Texas, Ball and Hastings (1912) observed that grain sorghum so well adapted to that region, had not been grown largely because of failure to set grain due to sorghum midge infestation. In Louisiana, Gable et al. (1928), and Walter (1953) considered the sorghum midge to be the worst insect attacking grain sorghums. They observed that when the sorghum midge was especially abundant, a yearly loss of approximately 20% of the crop occurred, and in years particularly favorable to the

Figure 2. Healthy and sorghum midge damaged sorghum heads.
A. Healthy, B. Damaged.

B
A

midge, no grain was produced. Callan (1945) stated that the sorghum midge was the most important insect pest known to attack sorghum and that in any new country into which the midge was introduced, it was likely to become a serious pest. This was confirmed in Ghana (Bowden and Neve, 1953; Bowden, 1965), in Queensland, Australia (Passlow, 1954; Greenup, 1974), in Nigeria (Harris, 1961), and in Argentina (Parodi, 1966). In Ghana damage on late flowering sorghum was estimated at 80% of the total crop production, in Queensland, Australia, the damage was described as considerable while in Nigeria it was valued at 5.5 million dollars per year.

Montoya (1965) in Texas reported that the sorghum midge had gained significant importance as a pest of grain sorghum in the United States, and that the insect had destroyed at various times from 10 to 91% of the grain sorghum crop. Harding and Hogg (1966) agreed with Montoya's (1966) assessment and regarded the sorghum midge as the greatest potential insect pest of grain sorghum in Texas, estimating that damage in the Texas High Plains was about 4-7 million dollars per annum. But Stanford et al. (1972) at a later date estimated the damage at 10 million dollars.

In Tifton, Georgia, Wiseman and McMillian (1969, 1970) reported that damage caused by the sorghum midge reached 89% in late plantings (June). In California (Tulare County), Summers et al. (1976) reported a loss of 0.5 million dollars and that at times, especially in late plantings, sorghum midge damage was so severe that the remaining crop was not worth the cost incurred in harvesting. In Mississippi, Green et al. (1975) observed that the sorghum midge, when present in large numbers, may completely destroy small plantings and also added that late planted

sorghum may be vulnerable to damaging midge population that build up in the surrounding area.

In India, the sorghum midge is considered to be posing a serious threat to grain sorghum. This was particularly so after the introduction of late flowering hybrids, diversification of varieties and intensive cultivation under multiple cropping system. Pradhan (1969) reported loss in yield of 83.7%. Jotwani et al. (1972) in three consecutive years estimated losses of 10.0, 15.1, and 19.8%, respectively. Thimmaiah et al. (1974) reported 48.2% damage and Rao (1976) at Delhi, India, showed that one single female midge could cause 6.5% damage to the spikelets.

In the Sudan, Africa, damage to grain sorghum was estimated at 25% (Cowland, 1936); and in Senegal, West Africa, Coutin (1970) reported a loss of 50-59%. Callan (1940) reported that the sorghum midge was a serious pest in Trinidad and the West Indies, causing severe losses to sorghum crops.

Distribution, Host Plants and Factors Causing Outbreaks

Distribution

The sorghum midge has been recorded from several tropical and subtropical countries throughout the world (Geering, 1953; Callan, 1945). Harris (1969) reported that the world distribution of the sorghum midge ranged from Italy and Nebraska (USA) in the northern hemisphere to New South Wales (Australia) and Buenos Aires (Argentina) in the southern hemisphere, and that its distribution around the tropics is virtually continuous (Figure 4). Harris (1964) compiled a record of the earliest known occurrence of the midge in several countries (Table 1).

Table 1. Contarinia sorghicola (Coquillett) recovered from herbarium specimens of the genus Sorghum. Source: Harris (1964). Bull. Entomol. Res. 55(2):233-247.

Country	Previous earliest record	New record
USA	1895	----
St. Vincent	1910	----
Puerto Rico	----	1886
Venezuela	1948	----
Hawaii	1906	----
Australia	1928	1912
Indonesia	1948	----
Sudan (Anglo Egyptian Sudan)*	1930	1869
Nigeria	1929	1917
Ghana (Gold Coast)*	1930	----
Gambia	1952	1930
Malawi (Nyasaland)*	1950	1925
Uganda	1951	1926
Kenya	1952	----
Tanzania (Tanganyika)*	1952	1934
Zaire (Belgian Congo)*	----	1914
Zambia (Northern Rhodesia)*	----	1929
South Africa	1958	1932
Yemen Arab Republic (Aden)*	1952	1946
Ethiopia (Eritrea)*	----	1949

* Names in parenthesis refer to old names by which the respective country was then known at the time these records were made.

In the United States, the sorghum midge is well established throughout the southern and southeastern quarter of the country, and it has also been reported in the west in the San Joaquin Valley of California (Lange et al., 1961). Figure 3 illustrates the pattern of the sorghum midge distribution in the United States.

Host Plants

The sorghum midge attacks all species of the grain sorghum, sweet sorghum, and broomcorn; and also develops on Johnsongrass, Sorghum halepense (L) Pers., Sudangrass, Sorghum sudanense (Piper) Stapf, and various wild and semi-wild species belonging to the genus Sorghum (Harris, 1969). Wild grasses of other genera have been thought to be hosts of the midge, but in some cases the species of the midge had been misidentified, as the case of Andropogon gayanus (Kunth) in Africa (Harris, 1969). Only the members of the genus Sorghum, either cultivated or wild, are of any importance as primary or alternative hosts of the sorghum midge (Harris, 1969). Table 2 presents a list of the reported host plants of the sorghum midge in the world.

Factors Causing Outbreaks

The most important general factors favouring sorghum midge outbreaks are climate, sources of initial infestation of the crop, and extent of the subsequent build up within it (Harris, 1969). The midge is dependent on relatively high atmospheric humidity during the growing season and infestations tend to be most severe in humid areas. This was confirmed in India (Barnes, 1956), in Argentina (Parodi, 1966), in the USA (Walter, 1953; Barnes, 1956), and in Nigeria (Harris, 1961). In the United States attacks are heaviest in the more humid south and eastern states. In Nigeria, infestations are greatest in the valleys of the rivers Niger and Benue.

Table 2. Plants of the Family Graminae known to host the sorghum midge, Contarinia sorghicola (Coquillett).

Scientific Name	Common Name	Location	Reference
Andropogon gayanus Kunth	Wild Bluestem grass	India, Africa	Harris (1961)
A. gerardii Vitman*	Big bluestem	Florida	Daniels (1963)
Bothriochloa saccharoides (Swartz) Rydb. var. torreyana (Steud.) Gould*	Silver bluestem	Alabama, Texas	Harding (1965)
B. intermedia (R. Br.) A. Camus*	Medium size bluestem	Florida	Santos and Viana (1974)
Dichanthium sericeum (R. Br.) A. Camus	Queensland bluegrass	Australia, Texas	Passlow (1965)
Echinochloa crusgalli (L.) Beauv.*	Barnyard grass	Florida	Harding (1965)
Ergrostis curtpedicillata Buckl.	Gummy lovegrass	Texas, SW USA	Harding (1965)
Eleusine coracana (L.) Gaertn.*	Finger millet	Florida	Geering (1953)
Lasiurus hirsutus (Forssk.) Boiss.	----------	India, Africa	Santos and Viana (1974)
Panicum miliaceum L.*	Broomcorn millet	Florida	Gable et al. (1928)
P. maximum Jacq.*	Guineagrass	Florida	Barnes (1956)
P. capillare L.*	Common witchgrass	Florida	Randolph & Montoya (1964)
P. hallii Vasey	Halls panicum	Texas, SW USA	Harding (1965)
Pennistetum polystachyon (L.) Schlt.	----------	Old World tropics	Barnes (1956)
Paspalum distichum L.*	Knotgrass	Florida	Harding (1965)
Sorghum sp.*	Sweet sorghum	Florida	Gable et al. (1928)
S. halepense (L.) Pers.*	Johnsongrass	Florida	Gable et al. (1928)
S. sudanense (Piper) Stapf*	Sudangrass	Florida	Gable et al. (1928)
S. arundinaceum (Desv.) Stapf*	Wild sorghum	Florida	Harding (1965)
S. verticilliflorum (Steud.) Stapf*	Wild sorghum	Florida	Geering (1953)
Setaria sp.*	Foxtail	Florida	Dean (1911)
Sieglingia seslerioides Scribn.	-------	Texas, Alabama	Dean (1911)
Sorghastrum sp.*	Indian grass	Florida	Randolph & Montoya (1964)
Sporobolus cryptandrus (Torr.) A. Gray	Sand dropseed	US except SE	Harding (1965)
Tridens flavus (L.) Hitchc.*	Purple top	Florida	Walter (1941)
T. albescens (Vasey) Woot. & Standl.	White tridens	Texas	Randolph & Montoya (1964)

* Presence in Florida has been confirmed by the University of Florida Herbarium.

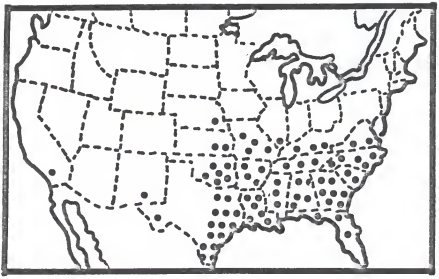


Figure 3. Distribution of the sorghum midge, Contarinia sorghicola (Coquillett), in the USA. Dots indicate infested areas. Source: Walter, E. V. 1953. U.S. Dep. Agr. Farmer's Bull. 1566.

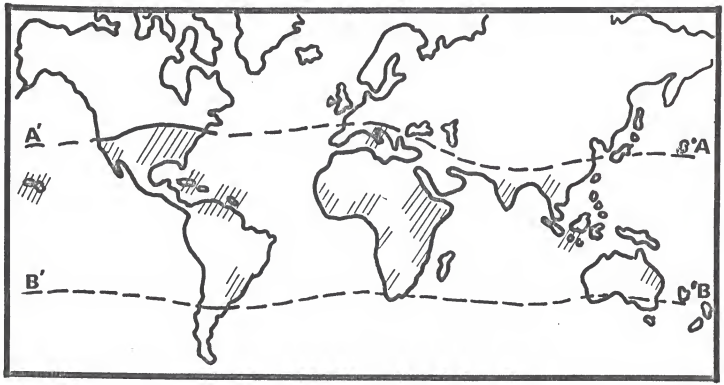


Figure 4. World distribution of the sorghum midge, Contarinia sorghicola (Coquillett). A'A and B'B lines represent the limits of distribution in the northern and southern hemispheres, respectively. Parallel lines indicate infested areas. Source: Harris, K. M. 1969. The sorghum midge. World Crops. 21(3):176-179.

In addition to a direct physical effect, humid areas may also have longer growing season and a greater abundance of wild hosts which would also favor the midge (Harris, 1969).

The source of initial infestation of the crop and extent of subsequent build up also affect outbreaks. Harris (1969) reported that although the number of diapausing larvae carried over from one season to the next in crop debris and on wild hosts was of obvious importance, the length of time during which flowering sorghums were present was even more important. The midges can only breed at flowering of the sorghum, and the longer flowers are available either in the crop or as self-sown volunteers, or as wild grasses, the greater is the potential increase of midge population during the season. A long build up through six or seven successive generations will usually ensure that late flowering main crop will be infested.

Population Control of the Sorghum Midge

Cultural

The sorghum midge has a concealed habit in which most of its life stages develop within the sorghum spikelet. It also overwinters within the spikelets and the adults emerge in spring to infest Johnsongrass and later, flowering sorghum. Many workers around the world believe that the best way to control the midge is through the use of cultural methods. Thus, as early as 1909, Herrick recommended early planting of Kafir-corn (sorghum) in Texas to avoid sorghum midge damage, and Dean (1911) suggested destruction of Johnsongrass by burning wherever it was found and the area where it was discovered plowed to prevent the grass from sprouting and putting on heads again. He also suggested

that stubbles be burnt and loose heads lying about buried to prevent carry over of diapausing larvae to next season crop. In addition, he recommended that sorghum heads that tended to bloom much earlier than the rest be destroyed as they provide initial breeding sites for the midge.

Ball and Hastings (1912) in Texas, showed that the best way to control the midge was to plant early so the sorghum could bloom before the midge became sufficiently abundant to cause injury. Walter (1941, 1953) recommended the following cultural methods some of which have been suggested by Dean (1911) and Gable et al. (1928): (1) use of pure seed of a uniformly blooming strain, (2) preparation of a good seedbed for a uniform crop stand, (3) spacing plant so to avoid uneven tillering, (4) selection of best planting time for the variety for uniform bloom, (5) prevention of nearby Johnsongrass from blooming prior to the sorghum crop, (6) removal of Johnsongrass by cutting and burning several days before the sorghum crop starts to bloom, (7) removal and burning of heads of sorghum that bloom earlier than the rest, (8) location of sorghum fields as far as possible from outside sources of infestation, e.g., Johnsongrass, Sudangrass, broomcorn, etc., (9) cultivation or burning of fields of Johnsongrass early in the spring to destroy midge larvae before emergence, (10) if two plantings are to be made near each other, they should be placed so the prevailing wind will blow toward rather than from the earlier field, and (11) burning or burying trash where sorghum grain is threshed before the spring emergence of midges.

Callan (1940, 1941) suggested the same methods enumerated above. Artherton (1941) advocated the same after discounting the use of chemicals. Passlow (1955, 1965) in Australia recommended an early

planting date to avoid flowering during heavy midge population in rainy summer season, and Matthee and Oberholzer (1958) in Pretoria, South Africa, recommended the aforementioned cultural methods after pointing out that the habit and life cycle of the midge make it difficult for chemicals to work properly. Adults are short lived and thus require repeated application of chemical which was considered non-economical.

Newman (1962) and Randolph and Montoya (1964) pointed out that farmers of the late 1950's in Texas, reduced overall losses by planting early. Harris (1961) in Nigeria, and Harris (1969) supported the use of cultural practices as the best techniques to reduce midge infestation when carried out as a joint effort by area wide sorghum farmers. Bowden (1965) in Ghana also supported the use of cultural methods to control the midge and discounted the use of chemicals, not only as tools which need skill to apply, but also as a burden to farmers.

In Texas, Harding (1965b) suggested that because concentration of adult midges in one location was of prime importance to development of injurious infestations, proper planting dates could avoid significant damage and offer the best possibility of reducing damaging midge build ups. Wiseman and McMillian (1968) in Tifton, Georgia, after conducting a planting-date-experiment, found a 3% and 89% grain damage in early (April) and late (June) plantings, respectively. Thus, they concluded that it might be possible to establish planting dates that will limit the damage done by the midge.

Thomas and Cate, Jr. (1971) in Texas, reported that early planting of sorghum was the most practical means of avoiding sorghum midge damage, and Cate and Bottrell (1971) said economic damage can be avoided by

planting early in the season or by selecting early maturing varieties so that bloom occurs before sorghum midge populations.

Summers et al. (1976) in California, using planting time and plant population to control the sorghum midge, found that early planting and low plant density gave higher yields and better midge control than late planting and more dense plant population. Green et al. (1975) in Mississippi, found that sorghum in plots planted early (April) suffered less damage (1%) than plots planted late (July) and which sustained an estimated grain loss of 98%. In Argentina, Parodi (1966) reported that cultural practices, such as adjustment of planting date to control the midge, were often used whenever possible.

Resistance

On sorghum varietes resistant to the sorghum midge, Bowden and Neve (1953) in Ghana, Africa, stated that Nunaba, a line with glumes that are non-opening at anthesis, was resistant. Indications were that a mechanical factor may have hindered the midge in its ovipositional attempts. However, Harris (1961) felt that the resistance of Nunaba resulted from a non-preference of the midge in the presence of two or more varieties. When Nunaba was grown alone, the midge readily oviposited on it. Geering (1953) found no true resistance to the midge in Uganda, Africa, and Walter (1953) stated that no varieties in the United States have shown any great amount of resistance to attacks of the sorghum midge. However, Harding (1965b) reported significant differences in the numbers of midges emerging from 12 varieties of sorghum tested in 1964 in the laboratory though no differences in seedset in the field were apparent. Wiseman and McMillian (1968) evaluated

216 sorghum lines for resistance to the sorghum midge in Tifton, Georgia, over a 5-year period, and found significantly fewer midges from each of 11 lines when compared to the most susceptible lines PC 16188, SPI 29166, DA 153, and CI 938. In 1970, Wiseman and McMillian tested 10 lines and showed that the adult midge preferred SP 12166 and CI 938 over ODC 19, even under heavy infestations. However, when the midges were abundant, they apparently did not discriminate among most sorghum lines.

In Brazil, Rossetto et al. (1975) showed that the sorghum variety AF-28 which has shown high level of resistance under field conditions, was resistant to sorghum midge attack under artificial infestation in cages, and Lara et al. (1977) confirmed this. Ross (1978) reported a midge resistant variety of sorghum, D-46, developed by B. Maunder of DeKalb seed company.

Chemical

Effectiveness of insecticides to control the sorghum midge is disputed by many workers including Artherton (1941) and Matthee and Oberholzer (1958). They argued that since the sorghum midge spends most of its life concealed within the spikelets, contact toxins provide little mortality. Furthermore, they added that the adult does not feed sufficiently to make it possible to use a poisoned bait, and that any such poisoned bait would probably be more dangerous to other organisms.

However, despite the difficulties encountered, insecticides are nevertheless used to suppress the sorghum midge population in sorghum. Walter (1953) reported that 5% DDT dust, at 25 lb/A, was used to suppress population of the midge at the time sorghum was blooming in the field. Passlow (1960) achieved 50-60% control when he sprayed DDT at 1.0 lb active ingredient (ai) per acre in about 15 gallons of water

in Queensland, Australia. Randolph and Doering (1964) in Texas showed that one or two applications of each of several insecticides tested against the sorghum midge reduced infestation and increased sorghum yields. Randolph and Montoya (1964) found that grain sorghum treated with carbophenothion against the sorghum midge had a higher yield than sorghum treated with other insecticides and the untreated check. Ward et al. (1972), in Argentina, reported that diazinon, toxaphene, and carbaryl were among the best insecticides against the midge. Harding (1965a) in Texas explained that differences in midge control were obtained in seven experiments in which performances of 42 insecticides against the sorghum midge were compared. Ashdown and Huddleston (1969) in evaluating 17 insecticides to control the midge noticed recognizable differences between adjacent plots of effective and non-effective insecticides. Harris (1969) suggested that weekly applications of persistent insecticides like DDT would give a reasonable degree of control, but warned residues on the harvested grain might well exceed permitted tolerances. He believed that systemic insecticides could be expected to give better long-term control.

Control of the sorghum midge population with chemicals depends on careful timing of the application during the bloom period (Thomas and Cate, Jr., 1971). The strategy is to apply the insecticides at 3-4 day intervals at 50-90% bloom within a 4-day period (Doering and Randolph, 1963; Randolph and Teetes, 1971; Cate and Bottrell, 1971; and Roth and Pitre, 1975).

Roth and Pitre (1975) found that at 4-day intervals beginning at 70% sorghum head emergence from the boots, diazinon, ethion, leptophos, and zolone gave good midge control. Cate and Bottrell (1971) showed

that the following insecticides were also significantly effective: (1) carbaryl + synergist at 1.0 + 0.5 lb/A, (2) suprocide at 0.25 lb/A, (3) carbaryl at 0.5 lb/A, (4) parathion at 0.5 lb/A, and (5) disulfoton at 0.5 lb/A.

Lara et al. (1976) in Sao Paulo, Brazil, reported several insecticides, each applied at 0.5 liter/ha, were efficient in controlling the midge: disulfoton, fenitrothion, dimethoate, methyl parathion, dichlorovos, and diazinon. Reis et al. (1977) in Minas Gerais, Brazil, found that by applying the following insecticides at 300 g/ha they obtained a good control of the sorghum midge with diazinon, carbofuran, carbaryl, chlorpyriphos, and ethion. Clorpyriphos was ranked the best among the treatments.

In India, Garg and Taley (1977), Agarawal et al. (1977), Murti et al. (1977) used several insecticides to control the sorghum midge and reported effective control with endosulfan, trithion, dursban, and carbaryl treatments.

Natural Enemies

A list of the reported natural enemies of the sorghum midge is presented in Table 3. The first record concerning natural enemies of the sorghum midge was 15 years after its discovery in the USA. Dean (1910) reported that the sorghum midge was attacked by the hymenopterous parasite Aprostocetus diplosidis Crawford (Figures 21 and 22), and Tetrastichus sp., and by the Argentine ant Iridomyrmex humilis Mayr. Dean (1911) reiterated that the sorghum midge was sometimes abundantly parasitized by A. diplosidis which was more predominant and aggressive than Tetrastichus, though it was not sufficiently effective until late in

the summer. He also observed that the fly Psilopodinus flaviceps Aldrich preys on the sorghum midge. The fly rests upon a sorghum leaf blade conveniently located near a head and darts out frequently to seize adults of the sorghum midge which it devours immediately.

Woodruff (1929) reported the hymenopterous parasite Eupelmus popa Gir. attacking both the larvae and pupae of the sorghum midge. The parasite was discovered in Texas in 1920 by Gable as recorded by Gahan (1922). But Walter (1941) believed that introduction of the parasite into the USA could have been as early as 1909 in sorghum seeds from India.

Artherton (1941) in Queensland, Australia, reported insectivorous birds, ants, and wasps attacking the sorghum midge, but not sufficiently effective to control the pest. In 1955, in Queensland, Australia, Passlow reviewed the records of the parasites of the sorghum midge and found the following: Eupelmus australiensis Gir., E. varicolar, E. popa, E. longicorpus, and Tetrastichus sp. He found the level of parasitism to range from 14.1% to 24.2%. Agreeing with Artherton (1941), Passlow (1955) concluded that parasitism was too low and the parasites were significantly ineffective to control the midge population. He believed that overwintering parasites emerged over a wider range of conditions than did their host from diapause and this resulting in a low level of parasitism.

Gable et al. (1928) found that birds and spiders play an important role in checking populations of the sorghum midge. They observed more than 20 species of spiders feeding on adults of the sorghum midge caught in their webs. They also found the Argentine ant and Solenopsis spp. destroying pupae and adults of the sorghum midge before they were able

Table 3. Natural enemies of the sorghum midge, Contarinia sorghicola (Coquillett).

Order	Scientific Name	Common Name	Role	Reference
Araneida	Diaca sp.		Predator	Harris (1961)
	Dictyna sp.		Predator	Walter (1941)
	Epeira pratensis Hentz		Predator	Walter (1941)
	Metaperira labyrinthea (F)		Predator	Walter (1941)
	Phidippus audar (Hentz)	Jumping spider	Predator	Walter (1941)
	P. mystaceus (Hentz)		Predator	Walter (1941)
	Thomisus sp.	Crab spider	Predator	Harris (1961)
	Peucetia viridans (Hentz)		Predator	Personal observation
	Chiracanthium inclusum (Hentz)		Predator	Personal observation
	Leucage venusta (Walckenaer)		Predator	Personal observation
	Pardosa mitvinae (Hentz)	Wolf spider	Predator	Personal observation
	Lycosa lenta Hentz	Wolf spider	Predator	Personal observation
Odonata	Argia sp.	Damselfly	Predator	Walter (1941)
	Pantala hymenaea (Say)	Dragonfly	Predator	Walter (1941)
Hemiptera	Geocoris punctipes (Say)		Predator	Walter (1941)
	Orius insidiosus (Say)	Flower bug	Predator	Walter (1941)
	Zelus socius Uhler		Predator	Walter (1941)
Diptera	Atomosia puella Wied	Robber fly	Predator	Walter (1941)
	Psilopodinus flaviceps Aldrich		Predator	Walter (1941)
Hymenoptera	Aprostocetus diplosidis Crawf		Parasite	Dean (1911)
	Eupelmus sp.		Parasite	Harris (1961)
	E. australienses Gir.		Parasite	Passlow (1955)
	E. longicorpus Cir.		Parasite	Passlow (1955)
	E. popa Gir.		Parasite	Woodruff (1929)
	Tetrastichus sp.		Parasite	Walter (1941)
	T. venustus		Parasite	Wiseman and McMillian (1970)
	Pheidole sp.	Ant	Predator	Walter (1941)
	Solenopsis geminata (F)	Fire ant	Predator	Walter (1941)

to fly. The ant, Tapinoma indicum Forel, has been reported a predator of the sorghum midge in India (Taley and Garg, 1976).

In Nigeria, Harris (1961) reported two new species of spiders, Thomisus sp. and Diaca sp. These natural enemies exerted little effect on the sorghum midge except in late summer. Matthee and Oberholzer (1958) and Geering (1953) reported the same effect in Pretoria, South Africa, and East Africa, respectively.

In Texas, Harding (1965b) reported E. popa and Tetrastichus and a number of predators which included Orius insidiosus (Say), ladybird, lacewing larvae, an unidentified mite, damselfly, and an assassin bug. He remarked that these natural enemies, though always present in the field, were not in sufficient numbers to prevent the occurrence of the sorghum midge infestation, and he doubted their efficiency once the sorghum midge infestation had built up. Rogers (1977) reported the same natural enemies found by Harding (1965b) in Texas.

Wiseman and McMillian (1970) reported that parasitism was not greater than 16% in Tifton, Georgia. Damaged seeds with parasite exit holes were only 13% of the total seeds destroyed.

Management

Rabb (1970) defined pest management as the reduction of pest problems by actions selected after the life systems of the pests are understood and the ecological as well as economic consequences of these actions have been predicted as accurately as possible to be in the best interest of mankind.

From this definition, it is clear that pest management embraces a broad ecological and economic base guided by two main principles:

(1) consideration of the life system of the pests, and (2) need to establish and utilize critical injury levels.

Regarding the sorghum midge, Doering and Randolph (1963) and Harding (1965b) pointed out that damaging infestations of the midge generally develop after two or three consecutive midge generations in grain sorghum, and that late planted sorghum blooming after the development of these damaging infestations usually suffers heavy yield losses. Since the development of damaging infestations of the midge is dependent on progressive buildup late in the year, Teetes (1976) explained that early uniform planting of grain sorghum so that blooming occurred throughout the area during a relatively short period is important for possible escape from the midge.

Grain sorghum may be planted late and therefore may require insecticidal treatment to prevent loss. For these situations, insecticidal control decisions have to be based on economic threshold levels. Teetes (1976) explained that fields should be inspected daily for adult midges beginning when heads first start to bloom at the tip. Inspection could be conducted along the diagonals of the field shortly after sunrise using a plastic freezer bag. At least 30 plants should be examined in each field; however, a representative sample size depends on the size of the sorghum field. The bag should be slipped over the sorghum head and the head shaken 3-4 times to dislodge midges, and midges counted. Teetes (1976) recommends an insecticide treatment when the mean number of midge adults per head exceeds 1, and when 25-30% of the heads have begun to bloom. If adults are still active 3-5 days later, Teetes recommends a second treatment, and adds that three

applications at 3-day intervals may be justified if the yield potential is high and midges are abundant.

Teetes (1976) pointed out that the use of midge resistant sorghum is another good management tool. He explains that use of midge resistant sorghum not only provides an escape from midge damage, but also provides flexibility in time of planting, thus allowing for more use of natural resources, e.g., rainfall.

Risk involved in indecision or improper decision to suppress the midge could be costly as explained under the subtitle, "Damage Symptoms and Economic Infestation," on page 12.

CHAPTER 3

BIONOMICS AND POPULATION DYNAMICS OF THE SORGHUM MIDGE, *Contarinia sorghicola* (COQUILLETT), ON GRAIN SORGHUM *Sorghum bicolor* (L) MOENCH

Introduction

This chapter presents studies on bionomics and behavior of the sorghum midge which relate to manner and time of the midge's invasion of a sorghum field, pattern of the sorghum head infestation, and temporal emergence of midges from sorghum heads. The chapter also presents studies on stages of the sorghum head most susceptible to midge attack and dynamics of the midge population within a sorghum crop.

In 1965, Harding remarked that information on an insect pest was prerequisite to an efficient control program. He also pointed out that such information was necessary to evaluate suggested control approaches. Travis (1977) explained that when factors regulating or governing changes in populations of a pest species were known, then they could be better manipulated to the detriment of the pest. The information that is to be derived from this study is therefore considered to be important so far as it bears relevance and significance to midge control programs.

Experimental work was done at the University of Florida Agricultural Research and Education Center, Quincy, Florida, in 1975 on five plots, 64.0 m x 6.4 m each with 91.4 cm between rows (Figure 5). Planting of the plots with the sorghum hybrid, DeKalb E-57, using a hand-planter began on 15 April 1975 on Plot 1. Planting was continued plot by

plot at 2-week intervals until 15 June 1975. The seed rate was ca 9.0 kg/ha. Post-planting weeds (sickle-pod) were removed by hand.

Sorghum Midge Invasion Experiment

Materials and Methods

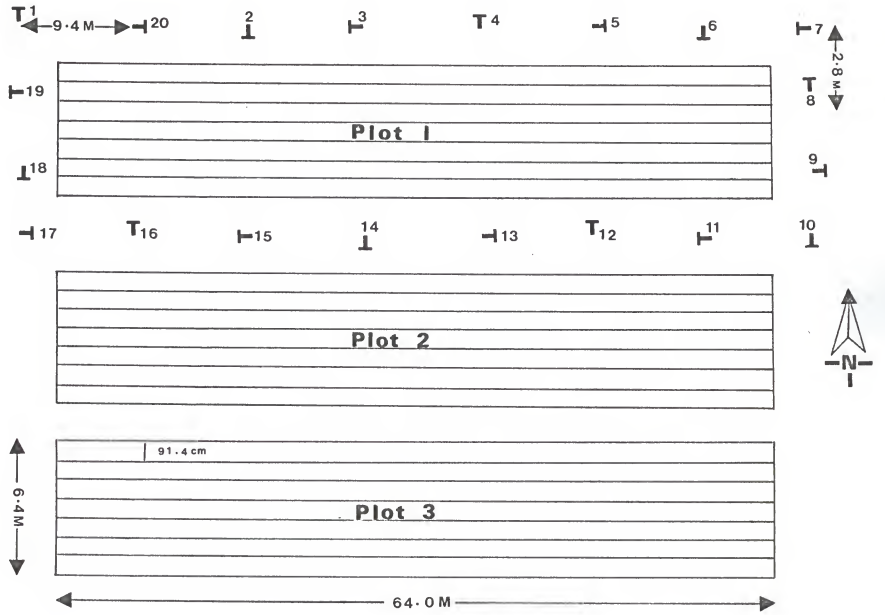
The objective of this experiment was to determine the manner and time at which sorghum midge invades a sorghum field. Information derived from this study, as previously mentioned, was considered to be useful in planning a control strategy for sorghum midge.

Plot 1, the first of the five plots to be planted, was chosen for the experiment. Sticky traps, consisting of yellow tags, 12 cm x 6 cm each, were used to trap the midges. Each trap was coated on one surface with a thin layer of Stikem Special^{R} and stapled onto one end of 1.3 cm x 3.8 cm x 137.2 cm stakes. The traps were placed on the perimeter of the plot 1 m from all four sides by driving the stakes vertically into the soil 6-8 cm deep.

Twenty traps, designated 1-20, were used. Eight were placed on each of the two long sides of the plot 9.4 m apart, and two on each of the two short sides of the plot 2.8 m apart. The traps were arranged so that the sticky faces were directed towards the cardinal directions—north, east, south, and west—as shown by the disposition of the letter "T" in Figure 5. The traps were erected in the field on 18 June (i.e., 7 days prior to sorghum head emergence) and were monitored daily for 15 days, from 18 June to 2 July 1975. Monitoring consisted of inspecting, recording numbers of midges, and removing and replacing the traps.

Data collected were compared with weather records on direction of movement and speed of the prevailing wind. Wind records taken between

Figure 5. Field layout showing three of five experimental plots with sticky traps, 'T', numbered from 1-20. Quincy, Florida, 1975.


T1
9·4 M
20
2
3
T4
5
6
7
2·8 M
19
T8
Plot 1
18
9
17
T16
15
14
13
T12
11
10
Plot 2
N
91.4 cm
6·4 M
Plot 3
64·0 M

6:00 a.m. and 6:00 p.m. each day during the period of experimentation for the two wind parameters, were used because after emergence in the early hours of the morning (Summers, 1975), sorghum midges could be airborne during the 12 hour period of the day.

Results and Discussion

Based on the sticky trap catches, the sorghum midge began to invade the sorghum plots on 25 June 1975 (Table 4). Invasion started from the northern and western side of the sorghum plot, and despite continued invasion of the sorghum midge from the aforementioned directions, no midges were recorded on the traps facing east of the plot. Overall average number of midges during the 15 days of experimentation were 0.7 midges/day for the traps facing west of the sorghum plot, 0.5 for traps facing north, 0.3 for those facing south and 0.0 midges/day for the traps facing east.

Direction of movement of the prevailing wind between 6:00 a.m. and 6:00 p.m. during the period of experimentation, 18 June to 2 July, was south-east (SE), north-east (NE), and east (E), except during 3 days—19, 28, and 29 June—when the direction of movement shifted toward north-west (NW) of the sorghum plot. Wind speed between the two hours of the day, ranged from 2.4 to 11.4 km/h (Table 4).

Results of the study show that invasion of the sorghum crop by the sorghum midge occurred mostly from the west and north of the sorghum plot with slightly fewer midges from the south. Average midge numbers, as mentioned above, were 0.7, 0.5, and 0.3 midges/day, respectively (Table 4). Invasion seemed to coincide with sorghum head emergence from the boots because prior to head emergence, 18-24 June, no midges were recorded on any traps. But when sorghum heads started to emerge, midges began to appear on the traps on 25 June.

The prevailing wind appeared to control midge locomotion and dispersal and hence the direction of invasion. These observations are based on the weather records obtained on direction of movement of the prevailing wind and also on the cardinal directions at which midges were trapped. The direction of the wind movement, as mentioned earlier, was south-east, north-east, and east, and midges were caught on traps facing north, south, and west. Since these approximately were the directions from which the prevailing wind was blowing, it is concluded that wind transported the midges that were trapped.

Walter (1941), Harding (1965b), and Wiseman et al. (1972) studied flight movement of the sorghum midge. They found that although midges could move of their own locomotion within a sorghum field, wind was the main agent that dispersed the adult midge. The results of this work seem to agree that, in effect, wind is the main midge dispersing agent.

Knowledge of the manner and time of movement of an insect is important for effective control (Harding, 1965b). The knowledge gained in this study should, therefore, be useful in planning a management strategy to control the sorghum midge. The following points may be considered: (1) select a field site on the windward side (Walter, 1941), (2) plant a border crop around a sorghum field to trap and arrest invading midges, (3) treat peripheral areas of the sorghum field thoroughly with insecticides on the assumption that the more central parts of the field are less infested and could accordingly, receive less insecticides (Wolfenbarger, 1972).

These tactics, well planned, should result in improved and economical control of the sorghum midge, judicious use of insecticides, and reduction of potential hazards to beneficial insects and other forms of life.

Table 4. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), trapped on each of the cardinal directions, north, south, east and west, and wind data showing direction of movement and speed of the prevailing wind during the period 18 June - 2 July from 6:00 a.m. to 6:00 p.m., Quincy, Florida, 1975.

	Sampling date															
	Pre-head emergence period							Head emergence period				Post-head emergence period				
	18 June	19 June	20 June	21 June	22 June	23 June	24 June	25 June	26 June	27 June	28 June	29 June	30 June	1 July	2 July	
Direction of sticky traps	Number of sorghum midges/five traps															Avg. number of midges/ day
North	0	0	0	0	0	0	0	1	2	2	0	0	1	1	0	0.5
East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
South	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0.3
West	0	0	0	0	0	0	0	1	4	2	0	0	2	1	0	0.7
	Wind Data: 6:00 a.m. to 6:00 p.m.															
Wind direction	SE	NW	NE	SE	E	E	NE	NE	NE	NE	NW	NW	SE	SE	SE	
Wind speed (km/h)	3.2	3.5	2.4	6.7	11.3	11.4	5.4	3.4	3.0	3.4	2.5	3.0	6.3	7.1	7.9	

Pattern of Sorghum Head Infestation

Materials and Methods

The objective of this experiment was to determine the infestation pattern of sorghum midge for oviposition in the top, middle, and bottom parts of the sorghum head.

Forty sorghum heads, after complete emergence from the boot and 10-15 days exposure to natural sorghum midge infestation, were removed from Plots 3, 4, and 5 on 15 July, 15 August, and 15 September 1975. Each head was divided into three parts—top, middle, and bottom. One hundred spikelets were taken at random from each of the three parts and placed into 14.0 cm diam plastic petri dishes for the midges to emerge. The petri dishes were lined with moist filter paper to prevent desiccation of the spikelets and were covered with 14.5 cm diam plastic dish covers to prevent escape of emerging midges. Samples were held in the laboratory at 24±2° C and 75-80% RH. Sorghum midges that emerged from each portion of the head were counted and removed from the petri dishes. The petri dishes were cleaned of excessive moisture and the filter papers renewed after each count until midge emergence ceased. Data collected were subjected to analysis of variance and Duncan's multiple range test to determine if differences among means were significant.

Results and Discussion

The numbers of the sorghum midges that emerged from each of the top, middle, and bottom parts of the sorghum head, are shown in Table 5. No difference in midge emergence was recorded from the three parts of the sorghum heads caged on either 15 July or 15 September ($P = 0.05$). No difference was also found on sorghum caged on 15 August 1975. It,

therefore, appears that sorghum midges were not selective and uniformly infest the sorghum heads.

Thomas and Cate, Jr. (1971) and Green et al. (1975) reported that infestation of sorghum heads by the sorghum midge occurs mostly in pollinating portions of the head, and that pollination begins from the tip and progresses downward to the base of the head lasting about a week in a single head and 2-3 weeks in a sorghum field. This extended period of pollination could have been responsible for the apparently uniform infestation of the sorghum head since head samples for the study were removed from the field ca 3-5 days after pollination had been accomplished.

In programs involving midge control to prevent grain loss, these results could be of practical significance in that in the execution of such programs treatment of the whole sorghum head should be taken into consideration. If sorghum is to be sprayed, the entire head should be fully covered.

These results might also be important to detection and estimation of midge populations in sorghum fields. Samples of spikelets removed either from the top, middle, or bottom portion of the sorghum head to detect or estimate midge populations should yield unbiased results since no significant difference in infestation of the top, middle, and bottom parts of heads (Table 5). A squeeze device could be used to press the spikelets to detect presence of midge larvae or pupae (Montoya, 1965), and from these an estimation of the sorghum midge population could be made. Chundurwar et al. (1976) in India employed a similar principle and technique to estimate sorghum midge population on sorghum fields.

Table 5. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), that emerged during the period 15 July-15 September from the top, middle and bottom parts of sorghum heads. Quincy, Florida, 1975.

Location on sorghum head	Sampling date		
	15 July	15 Aug.	15 Sept.
	----------	No. of midges/100 spikelets	-------
Top	2.6 a[1]	8.6 a	3.9 a
Middle	2.6 a	10.6 a	4.3 a
Bottom	2.3 a	9.1 a	4.1 a

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Emergence of Adult Midges from Sorghum Heads

Materials and Methods

To determine the temporal emergence pattern of adult sorghum midges from sorghum heads, 10 sorghum heads, showing symptoms of sorghum midge damage, were removed from the field twice each week for 3 weeks. Sorghum heads were picked at 6:00 p.m. at each collection because minimal emergence occurred at this time. Each sorghum head was placed into a 0.5 liter capacity plastic bag to await midge emergence. The plastic bags were slipped over each sorghum head and secured around the peduncle with a rubber band. The peduncle bearing the enclosed head was inserted in a 250-ml plastic bottle one-half filled with water to slow drying of the sample. Samples were held in the laboratory at 24±2° C and 75-80% RH. Emerged midges in all samples were counted every hour using the following procedure:

a) the sample was removed from the 250-ml plastic bottle,

b) the enclosed sorghum head was shaken 2-3 times to dislodge midges inside the bag,

c) the bag was removed and closed tightly with a rubber band to prevent midges from escaping,

d) a second bag was slipped over the head and secured in place with a rubber band,

e) the head sample was replaced into the bottle,

f) midge counts were later made for each of the bags previously removed.

Results and Discussion

Emergence of the midge adults began in small numbers at about 3:00 and 4:00 a.m., and reached peak numbers at 8:00, 9:00, and 11:00 a.m. in the 3 weeks of test (Figure 6). A majority of the midges emerged before noon and by ca 1:00 p.m. over 90% of the sorghum midges had

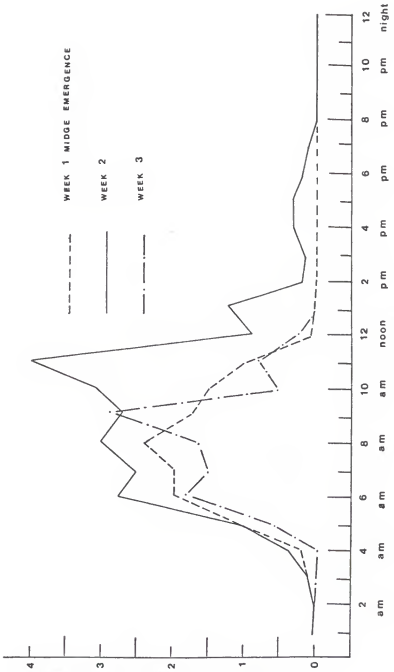
emerged irrespective of test weeks. However, emergence continued throughout the day, particularly in week 2, but the numbers emerging were negligible.

Previous workers have reported that sorghum midges emerged from sorghum heads in large numbers in the morning hours (Summers, 1975). The phenomenon is also confirmed in this work. Since pollinating spikelets are the most susceptible to midge infestation (Walter, 1941; Thomas and Cate, Jr., 1971; and Green et al., 1975), and since pollination occurs in early morning hours (Freeman, 1970), midges that emerge in the morning have more time to seek for oviposition spikelets in a susceptible stage. Moreover, Harding (1965b) indicated that sorghum midges do not oviposit after dark; therefore, early morning emergence provides the maximum number of daylight hours for host selection and oviposition.

These results are important to field sampling and scouting for sorghum midges. The data provide reliable guidelines for when to scout for sorghum midges. Scouting in the morning, 6:00 to 9:00 a.m., provides an opportunity to encounter midges in an active state on the sorghum heads. Since the sorghum midge spends most of its lifetime concealed in the spikelets, this opportunity is essential to make a reliable estimation of the sorghum midge population. Afternoon scouting would be less reliable since the chances of encountering adult midges are slight.

These results could also be of value in drawing up a timely spray schedule to control the sorghum midge. For instance, irrespective of damage done, a spray operation performed in the morning between 5:00 a.m. and 11:00 a.m., would result in substantial mortality to flying midges by contact. An afternoon spray, on the other hand, would be

Figure 6. Emergence of the sorghum midge, Contarinia sorghicola (Coquillett), from grain sorghum. Quincy, Florida. 1975.


WEEK 1 MIDGE EMERGENCE
WEEK 2
WEEK 3
Avg No. of Midges Emerged/Head/Hr
0
1
2
3
4
2 am
4 am
6 am
8 am
10 am
12 noon
2 pm
4 pm
6 pm
8 pm
10 pm
12 night
Time

non-economical because scarcely any midges move about on the sorghum heads then.

Susceptibility of Sorghum Heads to Midge Infestation after Exertion

Materials and Methods

This experiment was done to determine the most susceptible stage of the sorghum head to midge infestation after emergence from the boot. Knowledge of the relationship between the susceptible stage of the sorghum head and the sorghum midge is considered important for effective timing of chemical sprays against ovipositing female midges. Thomas and Cate, Jr. (1971) believed that 50-90% head bloom was the appropriate time to initiate chemical sprays. Roth and Pitre (1975) considered 70% head bloom appropriate. Other workers, however, think 30-50% bloom is the right time to start spraying (Anonymous, 1975b).

In the following study, 80 sorghum plants were tagged 7-10 days prior to boot initiation and head emergence. The plants were divided into groups (or replicates) of 20 plants each and were observed daily to note boot initiation. Plants which developed boots were immediately covered with brown-paper pollination bags. The open end of each pollination bag was twisted around the stem just below the head and tied with string to prevent midge entry in the bag.

On the day head emergence from the boot started, (Day 1), eight heads—two per replicate—were exposed to natural midge infestation for 24 hours by removing the bags at 6:00 p.m. and replacing them on the same heads at 6:00 p.m. the following day. Each day thereafter for 10 days, eight sorghum heads were similarly exposed until all 80 plants received head-exposure treatment by Day 10. Each group of heads exposed

on the same day was allowed 10 days after exposure and infestation for eggs of the midges to hatch and the larvae to develop before they were removed from the plant and placed in emergence cages. Sorghum heads receiving the same treatment, two from each replicate, were placed in a single cage and held under laboratory conditions of 24±2° C and 75-80% RH.

The midge emergence cages, 25.4 cm x 34.3 cm x 50.8 cm, were made of cardboard and fitted on one side with 2.5 cm diam by 4.8 cm plastic vials (Figure 7). The inside of each vial was coated with petroleum jelly to entrap the emerging midges. Midge counts in the vials were made every 2-3 days until emergence ceased.

Susceptibility of the sorghum heads was determined by counting the total number of midges that emerged from each exposure period.

Results and Discussion

Results of the study on susceptibility of sorghum to midge attack indicate that infestation of the heads began as early as Days 2 and 3 after head emergence from the boots. The infestation level significantly increased after Days 4, 5, 6, and 7 ($P = 0.05$). After Day 7, and through Day 10, the sorghum heads continued to be susceptible to midge attack but at significantly lower levels (Table 6).

This pattern of sorghum head susceptibility agrees with that reported by Doering and Randolph (1963) and by Thomas and Cate, Jr., (1971). Doering and Randolph's reports indicate that sorghum heads were most susceptible to midge infestation on the 3rd day after emergence from the boots. Thomas and Cate, Jr., showed that the 2nd through the 6th day was the most important period in a given head but in a sorghum field this period could extend to the 9th and 10th day.

Figure 7. Emergence cage for the sorghum midge, Contarinia sorghicola (Coquillett).

Table 6. Susceptibility of sorghum to the sorghum midge, Contarinia sorghicola (Coquillett), infestation after head emergence from the boot. Quincy, Florida, 1975.

Days after sorghum head emergence	No. of midges emerged/head
1	0.0 a[1]
2	0.5 a
3	1.5 a
4	21.0 b
5	17.5 bc
6	18.3 bc
7	14.3 c
8	4.3 a
9	1.8 a
10	2.0 a

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

The time 2nd through 10th day, of sorghum head susceptibility to midge attack, coincides with the duration of head pollination (Thomas and Cate, Jr., 1971). Since infestation is related to pollination of the sorghum head, an early insecticide treatment immediately after head emergence would ensure the presence of insecticides when oviposition activities begin. This would result in high midge mortality. However, insecticides must also be applied intermittently through the 10th day after sorghum head emergence. Three to 4-day intervals between applications as advocated by Doering and Randolph (1963), Randolph and Teetes (1971), Cate and Bottrell (1971) and Roth and Pitre (1975), are appropriate and can ensure maximum sorghum midge mortality.

Sorghum Midge Population and Sex Ratio

Materials and Methods

Sorghum midge control is generally preventive. To effectively and economically prevent loss to sorghum midge, a sorghum producer should understand not only the bionomics and behavior of the sorghum midge but should also know the time at which sorghum midge population constitutes an economic infestation (Thomas and Cate, Jr., 1971).

To determine the dynamics of the sorghum midge population on sorghum, midge population was sampled from the last week of June through middle of September 1975. Midges were sampled daily from 6:00 a.m. to 9:00 a.m. on the five sorghum plots described earlier. Timing the samples was based on the observation that adult midges emerge and are active in the early hours of the morning. A large size plastic freezer bag, about 1 liter capacity, was quickly placed over the sorghum head and closed tightly around the peduncle at the base of the head. Three to four

sharp raps or shakes of the head dislodged midges into the bag which was removed and closed. Twenty sorghum heads were sampled each day, midges counted and the numbers recorded.

During the period of midge sampling, June through September 1975, sex ratio of the sorghum midge was also determined. Since sex ratio is one of the intrinsic attributes of a species population (Odum, 1971), knowledge of the midge's sex ratio might be useful in explaining dynamics of the sorghum midge population. Hence, 20 sorghum heads at the milky stage of development were removed from each of the five plots on 15 July, 30 July, 15 August, 30 August, and 15 September 1975. The heads were placed in midge emergence cages similar to those described earlier, to allow the midges to emerge. Five heads, in four replicates, were placed in a single cage. All other procedures were the same as described under the preceding Experiments. Midges that emerged were sexed under a 25x magnification and the numbers of each sex group recorded.

Rainfall and temperature, during the period of study (June-September 1975), were monitored by the weather service of the Agricultural Research and Education Center, Quincy, Florida.

Results and Discussion

Results of the study on sorghum midge population show that by the end of June 1975 sorghum midges were present in the sorghum plots to disappear and appear again in large numbers on 14 to 17 and 20 to 24 July. (Figure 8B). Populations peaked on 16 and 21 July at 4 and 6 midges/head, respectively. The population then declined to zero by 24 July. From 3 to 22 August, a large midge population with several peaks occurred. The highest peak during the period, 25 midges/head, occurred on 11 August. By 28 August, the midge population had declined to zero

and was sustained at that level until 8 September. Two days later, the sorghum midge population peaked once more before finally dropping to zero by 13 September (Figure 8B).

Presence of the sorghum midge on sorghum by the end of June coincided with sorghum bloom in the plots planted in April. The coincidence seemed related to midge preference for blooming sorghum heads for oviposition as already discussed and reported by Newman (1962), Thomas and Cate, Jr. (1971) and by Green et al. (1975).

The midges, however, did not live long on the sorghum heads. Because of the short life span, 1 to 2 days, apparently they died after oviposition, thus, resulting in the midge's absence on the sorghum heads from 5 to ca 14 July (Figure 8B). The sorghum midge population then began to increase. Several population peaks appeared between July and September, but the most prominent peaks occurred on 21 July, 11 August, and 10 September. These peaks were the highest of the respective months and were separated from each other by almost an equal time interval. The first time interval was ca 16 days, from 5 to 21 July. The second was ca 18 days, from 24 July to 11 August, and the third time interval was ca 19 days, from 22 August to 10 September (Figure 8B).

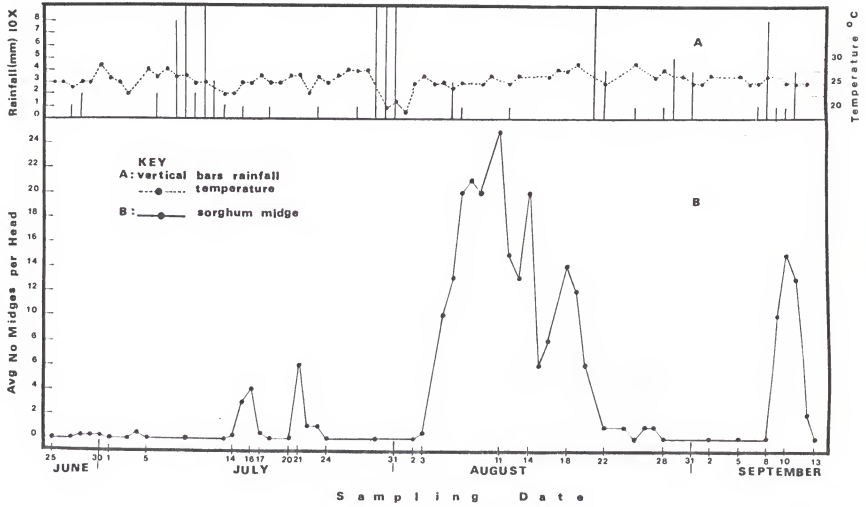
These time intervals are within the range of the duration (16 to 21 days) reportedly required for the sorghum midge to complete its life cycle under summer conditions (Dean, 1911; Walter, 1941; Geering, 1953; Harris, 1961; Doering and Randolph, 1963; Bowden, 1965; Taley et al., 1972; Barral et al., 1974; and Rao, 1976). Since these observations were made under summer temperatures of 25 to 30° C (Figure 8A), the peaks probably reflect successive generations. Therefore, three sorghum midge generations possibly developed during the period from 5 July to 13

September with the first generation occurring in July, the second in August, and the third in September.

The population level of the sorghum midge that occurred in July was lower than the levels of August and September (cf population peaks). Several factors probably contributed to these differences. For instance, in June, the midge population that initiated infestation of sorghum was small, less than 1 midge/head (Figure 8B). This undoubtedly contributed to the low midge population in July. Moreover, the weather was generally unfavourable. Rainfall was sporadic and below 20 mm most of the time except for eight precipitations which were above 70 mm. Temperature ranged from 25 to 30° C except at the end of July when a heavy rainfall lowered it to 22° C (Figure 8A). These relatively dry weather conditions probably affected the midge population. Harris (1969) pointed out that sorghum midges flourish well only under conditions of high humidity. A dry atmosphere has a negative effect on midge populations.

The prolonged length of time during which flowering sorghum was present in the field was considered to be responsible for the sorghum midge increase experienced in August and September. Notably, sorghum was in various stages of bloom from end of June to about middle of September 1975. This undoubtedly provided female midges with extensive breeding sites. The increase in midge population was therefore believed to be due to a cumulative buildup of the sorghum midge population in the sorghum field. Harris (1969) expressed a similar opinion in explaining causes of midge outbreak in fields of sorghum, and Harding (1965b) and Huddleston et al. (1972) explained that severe yield losses in late blooming sorghum due to midge attack was the result of midge buildup from early blooming sorghum.

Figure 8. Population fluctuation (B) of the sorghum midge, Contarinia sorghicola (Coquillett), on grain sorghum, and temperature and rainfall conditions (A) during the period June-September. Quincy, Florida. 1975.


Rainfall(mm) 10X
Temperature °C
A
B
KEY
A: vertical bars rainfall
temperature
B: sorghum midge
Avg No Midges per Head
JUNE
JULY
AUGUST
SEPTEMBER
Sampling Date

The other factor considered to have contributed to the increase in sorghum midge population in August and September was the sorghum midge sex ratio. Results of the sex ratio study (Table 7) indicate that female midges progressively increased over males in the course of the growing season. On 15 July, of the sorghum midges that emerged from caged heads, 32.7% were females. The percentage increased to 41.8 by 30 July, and to 58.0 and 60.8 by 15 and 30 August, respectively. By 15 September, female midges comprised 62.0% of the sorghum midge population. A shift in the midge's sex ratio in favor of females became apparent by 30 August (60.8%).

Summers (1975) observed a similar shift in sorghum midge sex ratios. He reported a shift from a female/male ratio of 1:1 in August to 2:1 in October, and in 1976 Summers and coworkers reported that a low percentage of sorghum midge females, among other factors, was responsible for the low levels of the midge populations experienced on sorghum in California in 1972. In this study, the steady rise in the percentage of female midges appeared to contribute to the sorghum midge buildup.

In summary, the results of this study show that the sorghum midge population buildup starts from a low level early in the season (June/July), and gradually builds up until high proportions are reached later in the season (August/September). Two factors favoring increase of the sorghum midge population were discussed: (1) prolonged period of time during which flowering sorghum was in the field, and (2) steady rise in the percentage of females in the course of the growing season.

In programs where management strategy is involved to suppress sorghum midge populations, a sorghum producer should adhere to cultural practices that reduce prolonged and uneven blooming of sorghum similar to those

suggested by Dean (1911), Ball and Hastings (1912), Gable et al. (1928) and Walter (1941) as outlined in Chapter 2.

Table 7. Total number of male and female sorghum midge, Contarinia sorghicola (Coquillett), that emerged from sorghum heads during the period 15 July - 15 September. Quincy, Florida, 1975.

Number of replicates	Sampling Date									
	15 July		30 July		15 Aug.		30 Aug.		15 Sep.	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
1	43	21	78	28	45	63	100	155	103	126
2	50	30	65	49	70	91	99	145	78	180
3	47	26	55	45	51	89	80	139	125	175
4	35	8	48	55	65	76	121	182	95	174
Total	175	85	246	177	231	319	400	621	401	655
Percent females	32.7		41.8		58.0		60.8		62.0	

CHAPTER 4

EFFECT OF PLANTING DATES, INSECTICIDES, AND SORGHUM HYBRIDS ON SORGHUM YIELD AND INFESTATION LEVEL OF THE SORGHUM MIDGE, *Contarinia sorghicola* (COQUILLETT)

Introduction

The sorghum midge, an important insect pest of grain sorghum in many countries in the world, has inflicted losses totalling millions of dollars per year (Geering, 1953; Harris, 1961, 1969; Thomas and Cate, Jr., 1971; Huddleston et al., 1972). The midge is most difficult to observe and control because of its concealment within the seeds of the sorghum spikelets. Many workers believe that adjustment of sorghum planting dates, timely application of insecticides, and use of midge resistant sorghum hybrids, are among the most effective ways to suppress midge populations in sorghum.

In Florida, there is paucity of data concerning the influence of planting date and selective insectides on sorghum midge control. This chapter reports results of tests conducted at Quincy, Florida, in 1976 to determine effects of sorghum planting dates and insecticides on sorghum midge infestation and sorghum yield. It also presents data gathered to determine the infestation level of midge on sorghum hybrids grown in several areas of Florida.

Planting Date Experiment

Materials and Methods

Field plots and preparation. Preparation of field plots began in February 1976 at the University of Florida Agricultural Research and Education Center, Quincy, Florida. Land was disked and incorporated with 560.4 kg/ha of 5-10-15 fertilizer and 90.6 kg/ha N from NH_4NO_3 source. Atrazine at 2.1 kg/ha was applied preplant to suppress weeds.

Plots for the respective dates were established on the date of each planting with the sorghum hybrid, DeKalb E-57. Plots were arranged in a randomized complete block design with four replicates. Each plot consisted of four rows 18.5 m long with 91.4 cm between rows. Two rows of the corn hybrid, Coker 77, were planted to separate adjacent plots and prevent migration of the sorghum midge (Figure 9).

The sorghum was planted by machine at a seed rate of ca 9.0 kg/ha. The planting dates were 15, 31 March, 15, 26 April, 16 May, 1, 15, 30 June, and 15 July 1976, respectively.

Sorghum midge infestation. Midge infestation was determined by counting adults of the sorghum midge that emerged from caged sorghum head samples. The sorghum heads, 25 per replicate, were removed at random from the two middle rows of each plot at the milky stage of development on 25 June, 1, 12, 26 July, 4, 12, 24 August, 2, and 12 September 1976, respectively. The heads were placed into 25.4 cm x 34.3 cm x 50.8 cm cardboard midge emergence cages (Figure 7). Emerging sorghum midges were collected in 2.5 cm diam and 4.8 cm plastic vials inserted into the sides of each cage. The inside wall of each vial was coated with petroleum jelly to entrap the emerging midges. Samples were held for 20 days emergence under laboratory conditions of

Figure 9. Sorghum planting date experimental plot showing corn hybrid Coker 77, as forming barriers A and B, against the sorghum midge, Contarinia sorghicola (Coquillett). Quincy, Florida. 1976.

A
B

24±2° C and 75-80% RH, and monitored daily by inspecting the vials and recording numbers and removing midges that emerged each 24 h period. Monitoring and counting were terminated when midge emergence stopped. Data were subjected to analysis of variance and Duncan's multiple range test to determine if difference among means was significant.

Yield loss. Yield loss was evaluated by using a visual rating scale. Ten sorghum heads, randomly selected in each of the four replicates, were examined visually and rated for grain damage on a scale of 0-10. Zero indicated no midge damage, and 1-10 indicated 10-100% grain loss.

Sorghum yield. This was determined by hand harvesting sorghum from 5 meters/row in the two middle rows of each plot. Sorghum heads were dried in a glasshouse at 35-40° C for ca 7 days to reduce grain moisture content to ca 10%. The sorghum heads were threshed in a Vogel^{R} single head thresher and the grains weighed.

Results and Discussion

Table 8 and Figures 10 and 11 present the data from the study. The data in Table 8 show no difference in numbers of sorghum midges recorded in the first three plantings (15, 31 March, and 15 April), although later midge recordings were significantly different. For instance, midges recorded per sorghum head from sorghum planted on 30 June and 15 July were significantly higher than midges from any earlier plantings ($P = 0.05$).

Grain loss per sorghum head increased from 0.8 to 94.0% as the planting dates were delayed (Table 8). Thus, sorghum planted on 15, 30 June and 15 July not only sustained 55-94% grain loss but suffered significant reduction in yield ($P = 0.05$). Compared to sorghum planted

Table 8. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), percent grain loss, and yield on sorghum hybrid, DeKalb E-57, planted on nine dates at Quincy, Florida, 1976.

Planting date	No. of midges per head	% grain loss per head	Yield kg/ha
15 March	2.8 a[1]	0.8 a	15,992 a
31 March	3.5 a	7.8 a	11,076 b
15 April	16.3 a	23.8 b	5,929 c
26 April	32.8 b	32.3 bc	5,458 c
16 May	35.3 b	34.0 bc	2,353 d
1 June	38.5 b	38.0 c	1,730 d
15 June	41.5 b	55.0 d	1,368 d
30 June	59.0 c	67.5 e	1,276 d
15 July	79.5 d	94.0 f	1,202 d

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

on 15 and 31 March, the yields obtained from the last three plantings (15, 30 June, and 15 July) were 1,368, 1,276 and 1,202 kg/ha versus 15,992 and 11,076 kg/ha, respectively (Table 8).

A coefficient of linear correlation was calculated to determine the relationship between number of midges that emerged per sorghum head and percent grain loss that resulted (Figure 10). A correlation coefficient, $r = 0.981$, was obtained which at $P = 0.05$ (t-test), indicated that significantly close relationship between the two variables existed. Examination of the coefficient of regression (Figure 10) showed that grain loss increased by 1.146% per unit increase in midge numbers.

Rao (1976), in India, reported that one female midge caused 6.5% damage. Summers et al. (1976), in California, in a plant population test showed that sorghum yield loss was ca 16 mg per unit increase in midge numbers at high plant density (39 plants/m), and that loss was ca 2 1/2 times less at low plant density (13 plants/m). Although the two workers reported different magnitudes of damage by a single midge on sorghum yield, their results are also reflected by the trend found in this study, i.e., grain loss increases as midge numbers increase.

Relationship between date of sorghum planting and date of 50% bloom, as they affect sorghum infestation by the sorghum midge, is illustrated in Figure 11. Sorghum planted on 15, 30 June, and 15 July, and which bloomed 50% on 13, 21, and 25 August, respectively, were not only highly infested (40-80 midges/head), but sustained loss above 50%. In contrast, sorghum planted on 15, 31 March, 15 and 26 April bloomed earlier in June/July. Infestation was below 40 midges/head, and grain loss sustained was less than 40% (Figure 11).

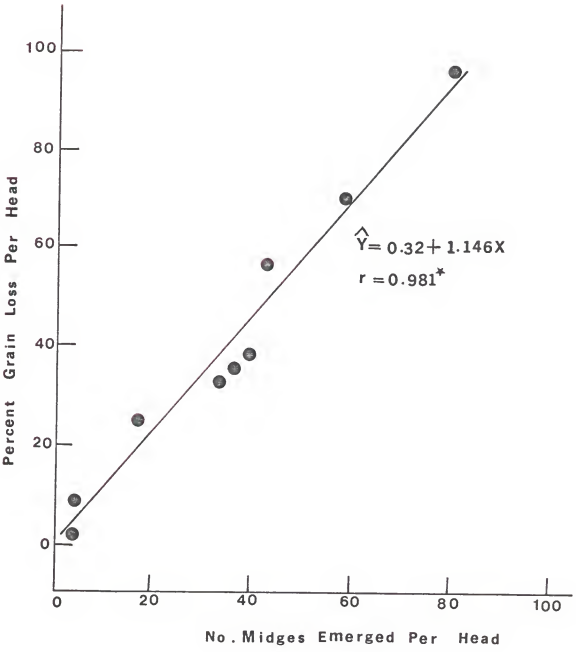
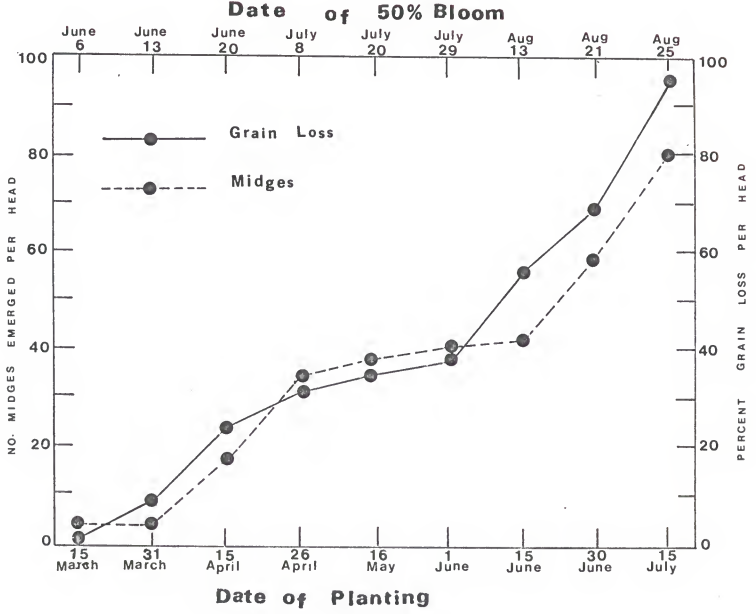


Figure 10. Regression relationship between number of midges emerged per sorghum head and percent grain loss per head. Quincy, Florida. 1976.

Figure 11. Relationship between date of sorghum planting and date of 50% bloom as they affect midge infestation and percent grain loss. Quincy, Florida. 1976.


Date of 50% Bloom
June 6
June 13
June 20
July 8
July 20
July 29
Aug 13
Aug 21
Aug 25
Grain Loss
Midges
NO. MIDGES EMERGED PER HEAD
PERCENT GRAIN LOSS PER HEAD
0
20
40
60
80
100
15 March
31 March
15 April
26 April
16 May
1 June
15 June
30 June
15 July
Date of Planting

Many workers have studied sorghum planting dates to avoid injurious midge populations in sorghum (Herrick, 1909; Ball and Hastings, 1912; Walter, 1941, 1953; Passlow, 1955, 1965; Matthee and Oberholzer, 1958; Harris, 1961; Newman, 1962; Randolph and Montoya, 1964; Bowden, 1965; Harding, 1965b; Wiseman and McMillian, 1968; Thomas and Cate, Jr., 1971; Cate and Bottrell, 1971; Green et al., 1975 and Summers et al., 1976). The conclusion reached was that early planting of sorghum was the most practical means of avoiding sorghum midge damage because early planted sorghum blooms before the midge population is sufficiently abundant to cause injury.

Results of this study agree with the conclusions above and confirm that major damage (over 50%) by the sorghum midge could likely be avoided by observance of planting dates (Table 8) because they are related to the flowering date of the sorghum hybrid (Figure 11).

A sorghum producer could, therefore, avoid damaging populations of the sorghum midge simply by planting sorghum early (middle of March to early April) in order to have sorghum bloom before appearance of midge populations.

Insecticide Evaluation

Materials and Methods

The experiment was done at the University of Florida Agricultural Research and Education Center, Quincy, Florida, in 1976 to determine effects of several insecticides on midge infestation and sorghum yield. Materials and methods used for field plots and cultural operations were similar to those used in the Planting Date Experiment.

Five insecticides each at two concentrations (rates) and a check-treatment were evaluated. The insecticides and the lower rate of application in kg of active ingredient (ai) per ha were: diazinon 0.1, methyl parathion 0.1, dimilin 0.1, FMC 33297 0.1, and carbaryl 0.6. The high rates were: diazinon 0.3, methyl parathion 0.3, dimilin 0.3, FMC 33297 0.3, and carbaryl 1.2.

Insecticides were applied from a tractor mounted sprayer with a boom equipped with four nozzles, one per row. The boom, held at ca 25-35 cm above plant heads and with a boom pressure of 30 psi, was maintained at a speed of 6.4 km/h to deliver ca 70.2 liters of spray mixture per ha. The plots planted on 2 June 1976 with the sorghum hybrid Dekalb E-57 were treated with insecticides when 30-50% of the sorghum heads were in bloom. Two applications were made, 31 July and 3 August 1976.

Post-treatment evaluation of midge infestation and sorghum yield was made using the same procedures described in the Planting Date Experiment.

Results and Discussion

Table 9 shows results of the insecticide test. No significant difference was recorded in sorghum yield in all treatments including the Check ($P = 0.05$). Numbers of midges per head in the insecticide treatments (except diazinon at 0.1 and carbaryl at 0.6 kg ai/ha) were significantly fewer than in the check. Concentration of the respective insecticides did not significantly influence midge numbers or sorghum yield at $P = 0.05$.

Ward et al. (1972), Roth and Pitre (1975), and Lara et al. (1976) reported that diazinon and carbaryl were the best insecticides against the sorghum midge. In this test, diazinon and carbaryl (except carbaryl

Table 9. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), and yield of sorghum, DeKalb E-57, after insecticides were applied to control the sorghum midge at Quincy, Florida, 1976.

Treatment	Dosage[2] (kg ai/ha)	No. of midges per head	Yield kg/ha
Diazinon	0.3	14.0 b[1]	7,009 a
Diazinon	0.1	15.0 ab	6,645 a
Check	---	29.0 a	6,625 a
FMC 33297	0.3	2.3 b	6,612 a
Methyl parathion	0.3	3.3 b	6,599 a
Carbaryl	0.6	15.8 ab	6,360 a
Dimilin	0.1	6.8 b	6,155 a
Carbaryl	1.2	5.8 b	6,009 a
Methyl parathion	0.1	5.5 b	5,804 a
Dimilin	0.3	10.8 b	5,565 a
FMC 33297	0.1	2.3 b	5,565 a

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

[2] Each insecticide was applied at 2 doses, low and high.

at 1.2 kg ai/ha) did not suppress midges as effectively as FMC 33297, methyl parathion and dimilin; yet plots treated with diazinon at low and high dosages ranked the best as far as sorghum yield was concerned (6,645 and 7,009 kg/ha, respectively). Plots receiving carbaryl treatments at 0.6 and 1.2 kg ai/ha produced 6,360 and 6,009 kg/ha of grain, respectively (Table 9). Diazinon, therefore, could be a preferred material to use against the sorghum midge. Since treating with either low or high dosages did not produce significant yield difference (Table 9), the low dosage is recommended. However, FMC 33297, methyl parathion, and dimilin (all at the low dosage, Table 9) have potential for midge control.

Sorghum Hybrid Experiments

In 1977, grain and silage sorghum hybrids were grown by the Agronomy Department of the University of Florida, in a state-wide test under Project FLA-AY-01590, to determine yield performance. A joint experiment with agronomists was undertaken to assess effects of the sorghum midge on the sorghum hybrids grown throughout the state.

Materials and Methods

Experimental plots were established at five Agricultural Research Centers of the University of Florida at Marianna (north-west Florida), Live Oak (north Florida), Gainesville (north central Florida), Ona (south-central Florida), and Immokalee (south-central Florida) in 1977. Fifty-two grain sorghum hybrids (physical characteristics of which are shown in Appendix Table 1) were planted at Marianna, Live Oak, and Gainesville; and 16, 17, and 18 silage sorghum hybrids were planted at Immokalee, Ona, and Gainesville, respectively.

Grain sorghum hybrids: field plots and cultural operations. At Marianna, Florida, land preparation to plant the grain sorghum hybrids began in February 1977 by disking and incorporating ca 1,016 kg/ha of Dolomite to adjust soil pH. Plots were arranged in a randomized complete block design with four replicates. Each plot consisted of two rows ca 6 m long, 91.4 cm apart. On 17 April, 672.5 kg/ha of 5-10-15 fertilizer was applied before sorghum planting on 21 April 1977, and after planting 98.6 kg/ha N was applied as side dressing. Atrazine, to suppress weeds, was applied on 22 April at 4.7 liters/ha, pre-emergence. Methomyl at 2.3 liters/ha was sprayed three times on 29 June, 6, 14 July 1977 to control sorghum head caterpillars.

Plots were irrigated on 6, 12, 18, 22 May, 9, 12, 16 June, and 1 July 1977, respectively. Water applied per irrigation was 25.4 mm. Sorghum was harvested on 8 and 9 August 1977 by taking 2.4 m from the middle of the plots. Sorghum heads were dried to within 10% grain moisture content, threshed and weighed.

At Live Oak, Florida, field layout and cultural operations for the sorghum test were similar to those performed at Marianna. However, 896.7 kg/ha instead of 672.5 kg/ha of 5-10-15 fertilizer was used to fertilize the sorghum, and 112.1 kg/ha N for side dressing. Sorghum was planted on 5 April and harvested on 2 August 1977.

At Gainesville, the grain sorghum hybrids were grown on a single row plots arranged in a randomized complete block design with four replicates. Plots were ca 5 m long and 91.4 cm apart. Land was disked and plowed on 18 March 1977, and 560.0 kg/ha of 10-10-10 fertilizer was incorporated. On 11 May, plants were side dressed with 224.1 kg/ha of

15-0-15 and later with 112.1 kg/ha N from NH_4NO_3 source. Another side dressing with 224.1 kg/ha N was applied on 12 June 1977.

Sorghum was planted on 28 March 1977 after application of 2.3 liters/ha carbofuran 10G for protection from soil insects. Methomyl was applied on 6 May, 30 May, and 2 June 1977 at 2.3 liters/ha to control head caterpillars. Plots were irrigated on 1, 15 April, 1, 13 June 1977. Water applied per irrigation was ca 38 mm. Sorghum was harvested on 27 June 1977.

Silage sorghum hybrids: field plots and cultural operations. Silage sorghum hybrids grown at Ona, Immokalee, and Gainesville had the land prepared in February/March 1977 with the following specifications for field layout:

a) Experimental design—randomized complete block design in all three locations.

b) Plot size—2 row plots at Ona, 3 rows at Gainesville, and 4 rows at Immokalee.

c) Number of replicates—four replicates in all three locations.

At Ona, the silage sorghum hybrids were planted on 3 March 1977 at a seed rate of 17.9 kg/ha in 45.7 cm row spacing. At Immokalee, planting was done on 2 March 1977 at a seed rate of 17.9 kg/ha, but in 76.2 cm row spacing. At Gainesville, silage sorghums were planted on 18 March 1977.

Fertilization practices at Ona consisted of 0-45-171 kg/ha N-P-K, which was broadcast and disked into the seedbed. At Immokalee, 0-49-186 kg/ha N-P-K was applied. After seedling emergence, 55.9 kg/ha N was applied. When plants were 40-45 cm tall, 112.0 kg/ha N were applied. After harvest, 112.0 kg/ha N were applied.

At Gainesville, fertilization practices consisted of similar operations as performed on the grain sorghum hybrids.

Weed control at Ona and Immokalee consisted of pre-emergence application of Atrazine at 2.0 kg/ha active ingredient. Paraquat was applied as a post directed spray at a rate of 0.3 kg/ha when sorghum was 45-60 cm tall. Immediately after harvest, paraquat at 0.3 kg/ha was sprayed over stubble. No herbicides were used to control weeds at Gainesville.

The experiment at Ona was irrigated with an overhead system and a total of 269.2 mm of water was applied during the growing season, March-November 1977. At Immokalee, a seepage irrigation system was used to supply the same amount of water. At Gainesville, five irrigations were applied totalling 190.5 mm of water for the whole growing season. A ratoon crop was allowed to grow from the sorghum stubble after the first harvest (22 July) and was harvested on 10 November 1977.

Sampling of sorghum midges and evaluation of their effects. Two methods were used to sample and evaluate midge effects on the sorghum hybrids. Method 1, a visual rating scale of 0-10, was used to estimate sorghum damage. Ten heads of each hybrid per replicate per location were randomly selected at the dough stage of development and examined visually for symptoms of midge damage (Figure 2). A rating of zero indicated no damage, and 1-10 represented 10-100% grain loss.

Method 2, involving rearing the sorghum midges from seed heads, was used to determine midge infestation level. Because of problems of handling 20 of the 52 grain sorghum hybrids in each location as well as all silage sorghum hybrids were sampled and evaluated by the following method. Four sorghum heads per hybrid per replicate per location were randomly selected and one-third of the head, the top portion, was

removed and placed into a 473.2-ml capacity (1 pint) ice cream carton fitted with a cover. Approximately 700 cartons containing ca 100 spikelet samples each were collected from all five locations during the period between 24 June and 15 October 1977 for midge rearing.

Samples were transported to the Entomology laboratory of the University of Florida, at Gainesville, in large cardboard containers and were held for 25-30 days emergence under laboratory conditions of 24±2° C 75-80% RH. Sorghum midges that emerged, died and remained in the container until it was emptied onto a 20.3 cm x 29.2 cm white paper and the insects counted. Data were transformed into $\sqrt{x + 0.5}$ prior to analysis.

Results and Discussion

Tables 10 through 13 give data from the study on the grain and silage sorghum hybrids. Data for individual locations can be found in Appendix Tables 2 through 6.

Grain sorghum hybrids. Table 10 shows three class ratings of grain damage for the 52 grain sorghum hybrids grown at Marianna, Live Oak, and Gainesville. The class ratings 1.3-1.4%, 0.9-1.2%, and 0.7-0.8% are also designated as "High," "Medium," and "Low," respectively, and are based on the overall average amount of grain damage caused by the sorghum midge in the three locations.

Based on these ratings, it can be noted that 6 grain sorghum hybrids sustained high grain loss, 30, medium loss, and 16, low grain loss (Table 10).

Percent grain loss by each of the 52 grain sorghum hybrids is shown in Table 11. Hybrids Funks G-399 and Young (Surgro)(FMC) Early Oro, sustained the highest percentage of grain loss, 1.4% each. ACCO D-2912

(ex-0912), Funks G-589, Young (Surgro) (FMC) Oro-DR, and Growers ML-135 suffered 1.3% grain loss each. These grain sorghum hybrids, not themselves significantly different at P = 0.05, sustained significantly higher grain damage than the following 11 hybrids (Table 11):

1. Funks BR-79
2. Ring Around (XL) Bird Go 68
3. Young (Surgro) (FMC) Oro-T
4. Ring Around (XL) 808GB
5. Young (Surgro) (FMC) Oro-Y
6. TE (Golden Acres) Hondo
7. Pioneer B-815 BR
8. Pioneer 8311
9. Funks G-642 GBR
10. Northrup King NK 2779
11. DeKalb D-46

Days to mid-bloom ranged from 65-69 with an average of 67.4 days (Table 11). Apparently days to mid-bloom did not influence effect of the midge on the grain sorghum hybrids. For instance, by comparing Funks G-399 and Young (Surgro (FMC) Early Oro, it can be noted that the former took 67 days to mid-bloom and sustained 1.4% grain loss whereas the latter took 65 days to mid-bloom and it too sustained 1.4% grain loss.

Further test, based on number of midges emerged per sorghum head (Table 12), indicated that ACCO D-2912(ex-0912), DeKalb BR-64, and Young (Surgro) (FMC) Early Oro, at P = 0.05, bore as many midges per head as McCurdy M 51-YG, the most susceptible hybrid in the group tested. Pioneer 8311, TE(Golden Acres) Hondo, DeKalb D-46, and Ring Around 808GB bore significantly fewer midges per head than McCurdy M 51-YG. Respective numbers were 0.8, 0.8, 0.7 versus 1.5 (Table 12).

Based on the two types of evaluation (i.e., visual rating scale for grain loss, and rearing for infestation), the grain sorghum hybrids ACCO D-2912(ex-0912), Young (Surgro) (FMC) Early Oro, and DeKalb BR-64 appeared consistently susceptible, whereas Pioneer 8311, TE(Golden Acres) Hondo, DeKalb D-46, and Ring Around 808GB appeared

less susceptible. The majority of the grain sorghum hybrids were average in their response to the sorghum midge (Tables 11 and 12).

Although the midge population and damage was small and represents only one growing season, the results are of value: (1) as background data on which to base further research for more information, and (2) as preliminary guidelines to avoid release of hybrids that could enhance the increase of a potentially devastating sorghum midge populations.

Silage sorghum hybrids. Table 13 shows results of the study on the silage sorghum hybrids. No significant difference in percent grain loss was recorded among the silage hybrids (P = 0.05) except between ACCO FS-401R and Funks G-605-S (13.3% vs 18.8%). Numbers of midges that emerged per head per hybrid were variable. The range was from 1.8 (Pioneer 942) to 9.8 midges/head (Northrup King 367).

Days to mid-bloom varied from hybrid to hybrid (Table 13). The earliest hybrid to bloom, Funks G-103-S, took 69 days to mid-bloom, and the latest, Northrup King 367, took 85 days to mid-bloom.

Comparison of midge numbers, percent grain loss, and days to mid-bloom in the silage and grain sorghum hybrids (Table 14) showed significant differences (P = 0.05). Number of midges was significantly higher (P = 0.05) in silage sorghum than in grain sorghum (5.0 midges vs 0.9 midges) and percent grain loss (15.7% vs 1.0%) was also higher. On the average, the silage hybrids required longer time to reach mid-bloom than the grains (76.5 days vs 67.4 days).

Since the silage sorghum hybrids are favorable hosts for the midge, but are grown for livestock fodder, harvest before they begin to bloom may be a practical way to reduce sorghum midge populations in an area.

Table 10. Susceptibility of 52 grain sorghum hybrids to the sorghum midge, Contarinia sorghicola (Coquillett), based on visual rating scale average for three Florida locations—Marianna, Live Oak, Gainesville, 1977.

% grain loss per head	Number of sorghum hybrids per class
1.3 - 1.4 (High level)	6
0.9 - 1.2 (Medium level)	30
0.7 - 0.8 (Low level)	16
Total	52

Table 11. Grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), and numbers of days to mid-bloom in 52 grain sorghum hybrids. Data represent average of three Florida locations—Marianna, Live Oak, and Gainesville, 1977.

Brand	Hybrid	Avg. % grain loss/head	Avg. number days to mid-bloom
Funks	G-399	1.4 a[1]	67 a
Young (Surgro) (FMC)	Early Oro	1.4 a	65 a
ACCO	D-2912 (ex-0912)	1.3 ab	66 a
Funks	G-589	1.3 ab	68 a
Young (Surgro) (FMC)	Oro-DR	1.3 ab	67 a
Growers	ML-135	1.3 ab	66 a
DeKalb	BR-64	1.2 abc	69 a
DeKalb	F-67	1.2 abc	69 a
ACCO	BR Y-93 (X-8418)	1.2 abc	68 a
Funks	G-522	1.2 abc	67 a
Funks	G-516BR	1.2 abc	65 a
McCurdy	M51 YG	1.2 abc	66 a
Funks	G-662	1.2 abc	67 a
McCurdy	Birds-off 91	1.1 abc	67 a
ACCO	DR 1085	1.1 abc	67 a
Ring Around (XL)	RA 811 GB	1.1 abc	69 a
Pioneer	8272	1.1 abc	67 a
Funks	HW 4060	1.1 abc	69 a
Northrup King	Savanna 5 (3101A)	1.0 abc	68 a
DeKalb	D-55	1.0 abc	67 a
TE (Golden Acres)	Y-101-R	1.0 abc	67 a
Growers	Exp-73022	1.0 abc	69 a
Funks	HW 2163	1.0 abc	69 a
Growers	GSA 1334 BR	1.0 abc	69 a
McCurdy	Birds-off 81	0.9 abc	67 a
Northrup King	Savanna 3	0.9 abc	65 a
Pioneer	8225	0.9 abc	66 a
ACCO	1029 A	0.9 abc	65 a
Funks	G-722DR	0.9 abc	69 a
ACCO	R1090	0.9 abc	66 a
Ring Around (XL)	RA747	0.9 abc	69 a
Funks	G-623GBR	0.9 abc	67 a
TE (Golden Acres)	Total-R	0.9 abc	68 a
Northrup King	NK 2778	0.9 abc	67 a
DeKalb	E59 +	0.9 abc	68 a
Young (Surgro) (FMC)	Oro	0.9 abc	67 a

Table 11 - continued

Brand	Hybrid	Avg. % grain loss/head	Avg. number days to mid-bloom
TE (Golden Acres)	Bird-a-boo 2	0.8 bc[1]	68 a
DeKalb	BR 65+	0.8 bc	69 a
DeKalb	D-60	0.8 bc	69 a
Pioneer	8454	0.8 bc	66 a
Growers	Exp-75005	0.8 bc	65 a
Funks	BR-79	0.7 c	67 a
Ring Around (XL)	RA Bird Go 68	0.7 c	69 a
Young (Surgro) (FMC)	Oro-T	0.7 c	68 a
Ring Around (XL)	RA 808GB	0.7 c	69 a
Young (Surgro) (FMC)	Oro-Y	0.7 c	67 a
TE (Golden Acres)	Hondo	0.7 c	67 a
Pioneer	B-815 BR	0.7 c	68 a
Pioneer	8311	0.7 c	67 a
Funks	G-642 GBR	0.7 c	67 a
Northrup King	NK 2779	0.7 c	66 a
DeKalb	D-46	0.7 c	69 a
Hybrid average		1.0	67.4

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Table 12. Numbers of sorghum midge, Contarinia sorghicola (Coquillett), and days to mid-bloom of 20 grain sorghum hybirds. Data represent average of three Florida locations—Marianna, Live Oak, and Gainesville, 1977.

Brand	Hybrid	Avg. number midges emerged/ head	Avg. number days to mid-bloom
McCurdy	M 51-YG	1.5 a	66 a[1]
ACCO	D-2912 (ex-0912)	1.3 ab	66 a
DeKalb	BR-64	1.2 abc	69 a
Pioneer	8454	1.2 abc	66 a
Young (Surgro) (FMC)	Early Oro	1.0 abc	65 a
Northrup King	Savanna 3	0.9 bcd	65 a
McCurdy	Birds-off 81	0.9 bcd	67 a
Funks	G-522	0.9 bcd	67 a
ACCO	R-1090	0.9 bcd	66 a
Ring Around (XL)	RA 747	0.9 bcd	69 a
Funks	HW 4060	0.8 cd	69 a
Northrup King	Savanna 5(x-3101A)	0.8 cd	68 a
Ring Around (XL)	RA-811GB	0.8 cd	69 a
Funks	G-399	0.8 cd	67 a
Pioneer	8311	0.8 cd	67 a
TE (Golden Acres)	Hondo	0.8 cd	66 a
DeKalb	D-46	0.8 cd	69 a
TE (Golden Acres)	Total-R	0.8 cd	68 a
Growers	ML-135	0.8 cd	65 a
Ring Around (XL)	RA 808GB	0.7 d	69 a
Hybrid average		0.9	67.2

[1] Column averages followed by the same letters are not significantly different at 5% Duncan's multiple range test.

Table 13. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), percent grain loss, and days to mid-bloom in 19 silage sorghum hybrids. Data represent average of three Florida locations—Immokalee, Ona, and Gainesville, 1977.

Brand	Hybrid	Avg. number midges per head	Avg. % grain loss per head	Avg. number days to mid-bloom
Northrup King	367	9.8 a[1]	14.6 ab	85 a
ACCO	FS-401R	7.5 ab	13.3 ab	71 ab
Funks	102F	7.1 ab	15.0 ab	75 ab
ACCO	FS-531R	6.5 abc	17.4 ab	82 a
McCurdy	F-75	6.0 bcd	14.7 ab	70 ab
DeKalb	FS-24+	5.8 bcd	14.7 ab	80 ab
Funks	G-605-S	5.9 bcd	18.8 a	72 ab
Taylor Evans	Silomaker	5.6 bcd	13.8 ab	71 ab
Ring Around	Silofil 35	5.4 bcde	14.4 ab	71 ab
Pioneer	947	5.0 bcde	15.9 ab	79 ab
Growers	30F	5.0 bcde	18.0 ab	77 ab
Funks	G-103-S	4.2 cdef	18.2 ab	69 b
Northrup King	Silomilo	4.2 cdef	15.1 ab	80 ab
DeKalb	FS-25+	3.8 cdef	18.3 ab	80 ab
Pioneer	923	3.8 cdef	14.6 ab	78 ab
Northrup King	300	3.5 def	15.6 ab	72 ab
Taylor Evans	TDN	2.8 ef	14.2 ab	82 a
McNair	Energy Plus	2.6 ef	16.4 ab	80 a
Pioneer	942	1.8 f	13.9 ab	79 ab
Hybrid averages		5.0	15.7	76.5

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Table 14. Relative numbers of the sorghum midge, Contarinia sorghicola (Coquillett), percent grain loss, and days to mid-bloom in grain and silage sorghum hybrids, Florida, 1977.

Type of sorghum	Avg. number of midges/head	Avg. % grain loss/head	Avg. number of days to mid-bloom
Grain	0.9 a[1]	1.0 a	67.4 a
Silage	5.0 b	15.7 b	76.5 b

[1] Column averages followed by the same letter are not significantly different at 5% (t-test).

CHAPTER 5

INFLUENCE OF NO-TILLAGE CROPPING AND NITROGEN FERTILIZER ON SORGHUM FLOWERING, INFESTATION LEVEL OF THE SORGHUM MIDGE, AND SORGHUM YIELD FOLLOWING RYE, Secale cereale (L.) AND LUPIN, Lupinus angustifolius L., WINTER CROPPING

Introduction

One outstanding advantage of no-tillage method of crop production besides savings in energy, equipment, time (Rask et al., 1967; Young, 1975), labor (Tripplett, Jr., 1976), and erosion prevention (Zinng and Whitfield, 1957) is feasibility to grow two or more crops in succession in the same piece of land in a single year whenever climatic conditions permit.

In Florida, the climate favors year round crop production. Combining the growing of winter crops of legumes or small grain for mulch, forage or green manure with no-tillage planting of grain sorghum in summer is feasible. However, it has been shown with other field crops, e.g., corn, Zea mays L. and soybean, Glycine max (L.) Merr., that despite its advantages over conventional method and its value in development of multi-cropping system, no-tillage method of crop production has created numerous insect pest problems because of induced modifications in ecological conditions in the fields (Musick, 1970; Gregory, 1974; Gregory and Musick, 1976). Regarding grain sorghum, no information is available to indicate that no-tillage cropping can be applied to produce grain sorghum without inducing changes that could affect growth of the plant and flowering and thereby predispose sorghum to sorghum midge

infestation. Notably, grain sorghum is sensitive to the sorghum midge at flowering and any factor that directly or indirectly delays sorghum flowering could expose the crop to devastating midge attack.

Knowledge of the effect of no-tillage cropping on time of grain sorghum flowering and midge infestation is therefore essential. This would help to avoid grain damage by the sorghum midge. Hence, in 1978 data were gathered to determine the influence of no-tillage cropping and nitrogen fertilizer on time of grain sorghum flowering, midge infestation, and sorghum yield following rye, Secale cereale (L.), and lupin, Lupinus angustifolius L., winter cropping. This chapter reports results of the study.

No-tillage and Nitrogen Fertilizer Experiment

Materials and Methods

The data were gathered from an agronomy experiment at the University of Florida Agronomy Farm, Green Acres, Gainesville, Florida. The experimental site, formerly covered with a 5-year old bahiagrass, Paspalum notatum Fleugge, was broadcast with 484 kg/ha of 5-10-30 fertilizer on 16 November 1977, and moldboard plowed to invert the bahiagrass sod. On 2 December 1977, the land was disk harrowed to provide a fine seedbed.

A latin square split plot design was laid out for the experiment. Main plots, measuring 6.0 m x 12.0 m each, in 5 x 5 latin square, included the main treatments: (1) rye for mulch no-tillage, (2) rye for stubble no-tillage, (3) lupin for mulch no-tillage, (4) lupin for stubble no-tillage, and (5) no winter crop conventional for a check. Subplots, 3.0 m x 6.0 m each, consisted of four levels of nitrogen fertilizer treatments: 0, 56, 112, and 224 kg/ha N from NH_4NO_3 source.

On December 1977, rye and lupin were planted by hand at 135 and 112 kg of seeds per ha, respectively. The seeds were covered by passing a disk harrow in the plots after planting, and on 17 January 1978 plots planted with rye were top-dressed by hand with 224 kg/ha N. When the rye and lupin plants were mature in the second half of March 1978, forage was removed from the appropriate plots to provide plots for the rye and lupin stubble no-tillage treatments, respectively. Plots receiving conventional tillage operations were rotovated and 22 and 56 kg/ha of P and K from triple superphosphate and murate of potash fertilizer sources, respectively, were broadcast over the area. Paraquat and x-77 surfactant were sprayed uniformly over the remaining plots to kill rye and lupin and provide plots for the mulch no-tillage treatments.

Growers ML-135 grain sorghum hybrid was planted on 17 April 1978 in rows 76 cm apart using a Brown Super Seeder and no-tillage subsoil planter. Seed rate was 9.0 kg/ha. Following planting and earlier soil analysis, the nitrogen fertilizer treatments were imposed on the sub-plots. One-half of the respective level of the nitrogen fertilizer was applied when sorghum plants were 10 cm high, and the other one-half when the plants were 60 cm tall.

When sorghum was 1 m high, atrazine and paraquat plus x-77 surfactant were applied on the entire area as post application for weed suppression. Plots were irrigated whenever necessary.

Sampling of the sorghum midge and evaluation of midge effect. The procedures for midge sampling and evaluation explained in Chapter 4 were followed. Yield loss was estimated by using a visual rating scale of 0-10, where zero represented no damage and 1-10 represented 10-100% grain loss.

Days taken by the grain sorghum to reach mid-bloom were monitored 30-40 days after sorghum planting. Sorghum was observed daily to note initiation of boots. Sorghum in a plot (or treatment) was considered to be in mid-bloom when 50% of the plants in the plot had 90-100% of the head emerged from the boot.

Results and Discussion

Results of the study are shown in Tables 15 through 18 and Figures 12 through 16. In Table 15 it can be noted that sorghum planted in plots with lupin stubble and lupin mulch no-tillage treatments attained mid-bloom within 64.5±1.5 days and 65.3±1.6 days, respectively. Sorghum in the conventional and rye no-tillage treatments required 68.3±1.5, 70.2±1.3, and 71.0±1.2 days, respectively. Percent grain loss in the lupin stubble and lupin mulch no-tillages was low, 4.3±0.7% and 4.8±0.9%, respectively. The highest grain loss, 12.1±4.3%, was experienced in the conventional tillage, and the highest yield, 4.1 metric tons/ha, was obtained from the lupin mulch no-tillage treatments.

Comparison of individual tillage treatments with regard to number of days to mid-bloom, grain loss, and sorghum yield (Figure 12), indicates that lupin mulch and lupin stubble no-tillage treatments were better than the rest in all three respects. Sorghum, in the aforementioned no-tillage treatments, flowered earlier (Figure 12A), lost least amount of grain (Figure 12B), and produced the highest grain yield (Figure 12C).

Since lupin is a legume and therefore fixes nitrogen in the soil, it can be argued that sorghum grown behind the lupin benefited from the "fixed nitrogen." Accelerated growth resulted in early sorghum flowering; thus, facilitating escape of the crop from damaging midge population.

Table 15. Days to mid-bloom, percent grain loss, and yield of the grain sorghum hybrid, Growers ML-135, under different production regimes, Gainesville, Florida, 1978.

Tillage treatments	Days to mid-bloom		% grain loss		Yield (metric ton/ha)	
	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D
Rye mulch no-tillage	70.2	5.7	9.4	12.7	3.6	---
Rye stubble no-tillage	71.0	5.3	10.0	13.3	3.3	---
Lupin mulch no-tillage	65.3	7.2	4.8	4.0	4.1	---
Lupin stubble no-tillage	64.5	5.1	4.3	3.4	3.5	---
Conventional tillage	68.3	6.9	12.1	19.2	3.3	---

Figure 12. Effect of no-tillage on number of days to 50% bloom (A), grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), (B), and yield (C) of the grain sorghum hybrid Growers ML-135. Gainesville, Florida. 1978.

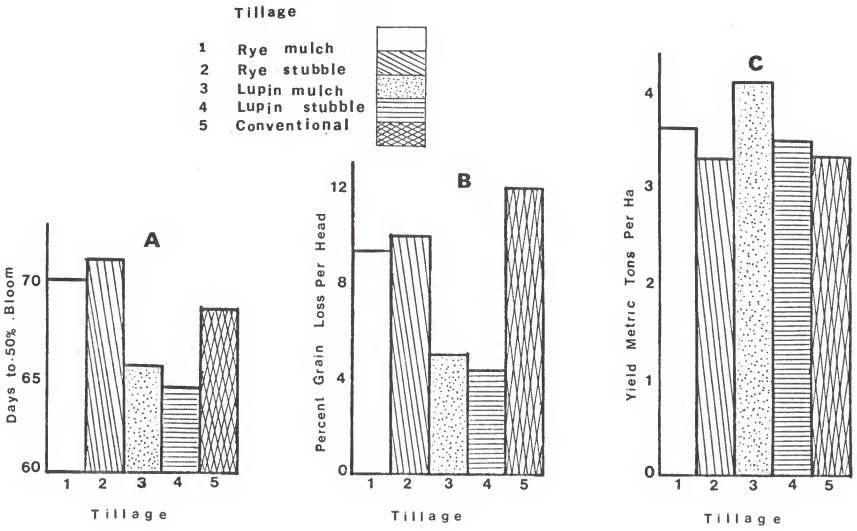
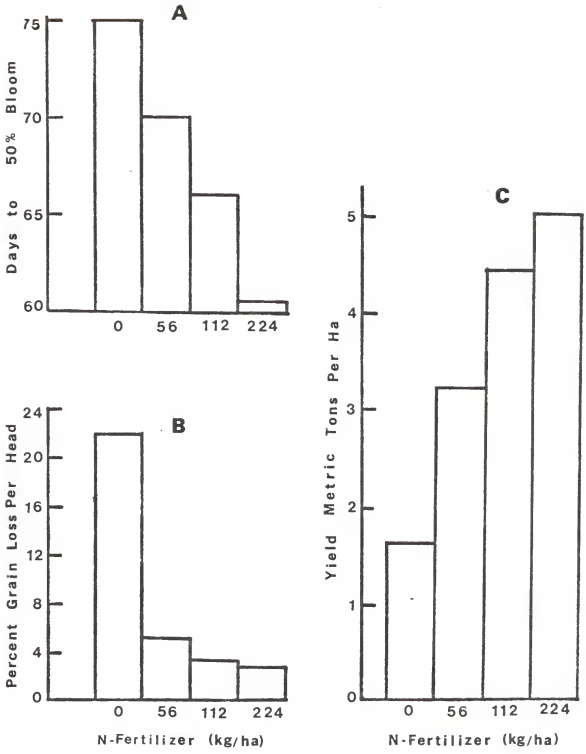

Tillage
1 Rye mulch
2 Rye stubble
3 Lupin mulch
4 Lupin stubble
5 Conventional
A
Days to 50% Bloom
70
65
60
1 2 3 4 5
Tillage
B
Percent Grain Loss Per Head
12
8
4
0
1 2 3 4 5
Tillage
C
Yield Metric Tons Per Ha
4
3
2
1
0
1 2 3 4 5
Tillage

Table 16. Days to mid-bloom, percent grain loss, and yield of the grain sorghum hybrid, Growers ML-135, under nitrogen fertilizer regime. Gainesville, Florida, 1978.

Nitrogen fertilizer levels (kg/ha)	Days to mid-bloom		% grain loss		Yield (metric ton/ha)	
	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S.D
0	75.2	3.9	21.6	18.3	1.6	---
56	69.8	3.0	4.6	3.4	3.2	---
112	65.9	3.4	3.4	2.9	4.4	---
224	60.5	4.2	2.9	1.6	5.0	---

Figure 13. Effect of nitrogen fertilizer levels on number of days to 50% bloom (A), grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), (B), and yield (C), of the grain sorghum hybrid, Growers ML-135. Gainesville, Florida. 1978.


A
Days to 50% Bloom
75
70
65
60
0
56
112
224
B
Percent Grain Loss Per Head
24
20
16
12
8
4
0
0
56
112
224
N-Fertilizer (kg/ha)
C
Yield Metric Tons Per Ha
5
4
3
2
1
0
0
56
112
224
N-Fertilizer (kg/ha)

In contrast, rye does not have the ability to fix nitrogen in the soil being a graminaceous plant. Therefore, sorghum in the rye plots had no accelerated growth, a later flowering date and hence greater attack by sorghum midge and higher grain loss.

In Table 16 and Figure 13, nitrogen fertilizer influence on the number of days to mid-bloom, grain loss, and sorghum yield, as reflecting effects of the subplot treatments, is shown. As nitrogen fertilizer level increased from 0 to 224 kg/ha, days to mid-bloom decreased (Figure 13A). Percent grain loss decreased also (Figure 13B). Contrastingly, sorghum yield increased with each added increment of nitrogen fertilizer (Figure 13C).

Responses of no-tillage treatments with nitrogen fertilizer levels on number of days to mid-bloom, grain loss, and sorghum yield are shown in Tables 17 and 18, respectively, and Figures 14 through 16.

In Table 17 and Figure 14, it can be noted that whereas sorghum in the rye no-tillage (mulch or stubble) treatments took more days to reach mid-bloom at each added increment of nitrogen fertilizer, sorghum in the lupin (mulch or stubble) treatments contrastingly took less time (Figure 14). However, days to mid-bloom generally decreased in all tillage treatments as the nitrogen fertilizer level increased.

Table 18 and Figure 15 show responses of the interactions between no-tillage treatments with nitrogen fertilizer levels on grain loss. At zero nitrogen level, percent grain loss in the lupin no-tillage (mulch or stubble) treatments was markedly less than in the conventional and rye no-tillage treatments (Figure 15). At 56 kg/ha, and as the amount of the fertilizer increased, percent grain loss in all tillages

decreased to within 2.5-7.5% with differences between tillages lying closely together (Figure 15).

Yield responses illustrated in Figure 16 show that with each added increment of nitrogen fertilizer, sorghum yield in all tillages increased. But over all, sorghum planted in the lupin mulch no-tillage plots ranked the best.

All tillage-nitrogen interactions examined in this study appear to show responses more favorable to sorghum planted in the lupin no-tillage (mulch or stubble) treatments than to sorghum planted in the conventional or rye no-tillage treatments. The argument presented earlier, that lupin is a legume and therefore fixes nitrogen in the soil while rye does not, probably accounted for the favorable responses generated by the lupin no-tillage plots.

In summary, the study suggests that no-tillage production of grain sorghum is better (with regard to midge damage) when sorghum is planted after lupin (either mulch or stubble) than when it follows rye or conventional tillages (Figure 12). The study also indicates that under conditions of the experiment, 56 kg/ha, applied at seedling time, may be the least quantity of nitrogen fertilizer required by the crop to grow rapidly and ensure early flowering and escape from midge damage (Figures 14 and 15).

Table 17. Days to mid-bloom by the grain sorghum hybrid, Growers ML-135, under no-tillage and nitrogen fertilizer regimes, Gainesville, Florida, 1978.

Tillage treatments	Days to mid-bloom at nitrogen fertilizer level (kg/ha)							
	0		56		112		224	
	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D
Rye mulch no-tillage	78.0	2.9	72.0	1.9	66.4	0.8	64.2	0.6
Rye stubble no-tillage	77.8	2.0	71.9	3.2	69.4	2.4	64.8	1.0
Lupin mulch no-tillage	73.6	2.0	68.5	1.7	63.3	4.1	55.6	1.5
Lupin stubble no-tillage	69.7	2.4	66.8	1.6	64.0	3.6	57.7	2.1
Conventional tillage	77.0	2.6	70.0	3.0	66.2	1.8	60.0	4.2

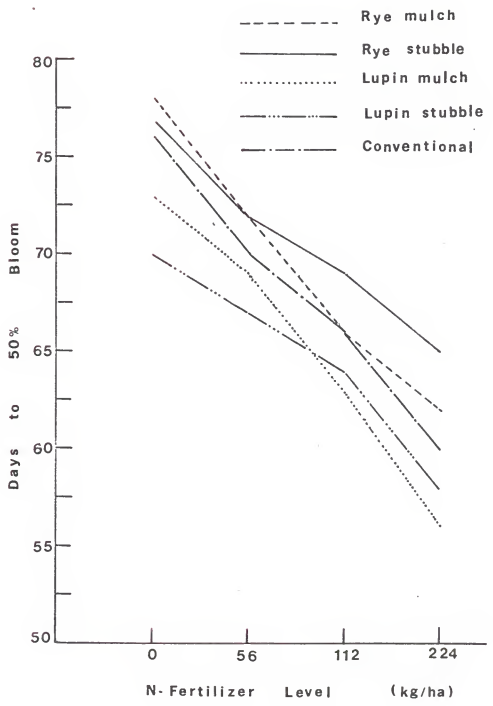


Figure 14. Effect of no-tillage and nitrogen fertilizer interaction on the number of days to 50% bloom of the grain sorghum, hybrid, Growers ML-135. Gainesville, Florida. 1978.

Table 18. Percent grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), in the grain sorghum hybrid, Growers ML-135, under no-tillage and nitrogen fertilizer regimes, Gainesville, Florida, 1978.

Tillage treatments	% grain loss at nitrogen fertilizer level (kg/ha)							
	0		56		112		224	
	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D
Rye mulch no-tillage	26.8	13.3	5.2	3.6	2.4	0.8	3.2	1.8
Rye stubble no-tillage	27.6	16.6	6.4	5.5	3.6	2.9	2.4	1.7
Lupin mulch no-tillage	8.8	3.6	3.6	1.7	4.8	5.0	2.0	2.0
Lupin stubble no-tillage	7.6	4.8	2.8	1.1	3.2	3.0	3.6	1.7
Conventional tillage	37.2	26.3	5.2	3.0	2.8	1.1	3.2	1.1

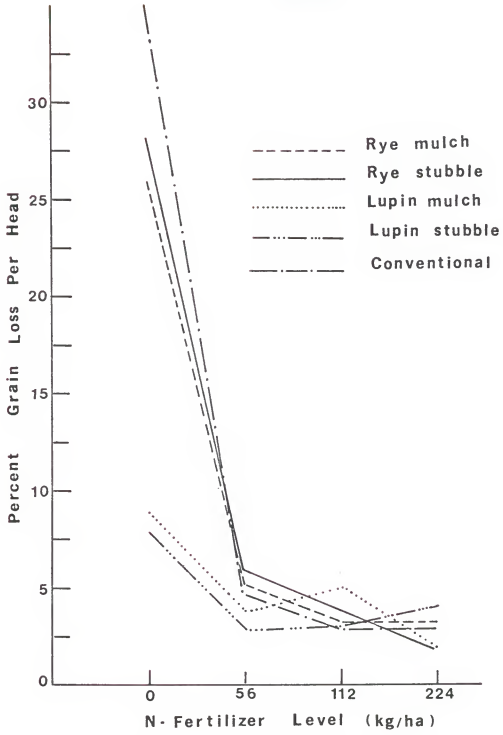


Figure 15. Effect of no-tillage and nitrogen fertilizer interaction on grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), in the grain sorghum hybrid, Growers ML-135. Gainesville, Florida. 1978.

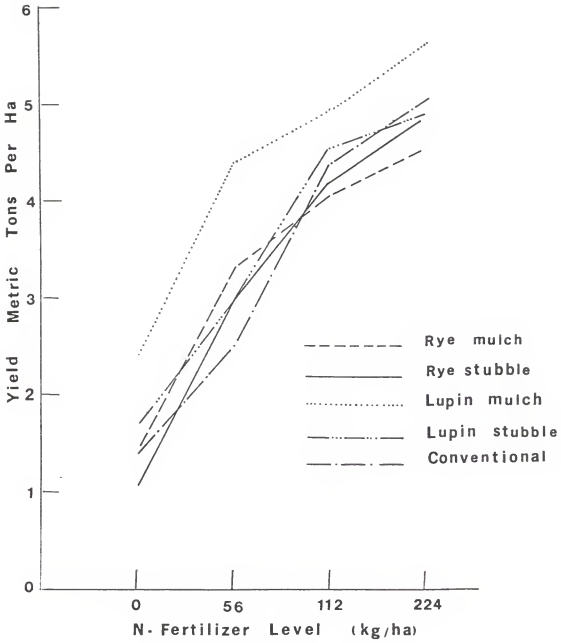


Figure 16. Effect of no-tillage and nitrogen fertilizer interaction on yield of the grain sorghum hybrid, Growers ML-135. Gainesville, Florida. 1978.

CHAPTER 6

CONCLUSION

The study covered a number of areas about the sorghum midge: bionomics and behavior of the midge, effects of sorghum planting dates, insecticide evaluation, susceptibility of sorghum cultivars, and effects of no-tillage method of grain sorghum production. The work was done to gain knowledge of the midge and the influence of the aforementioned factors on the midge in Florida. The work was also done because grain sorghum is becoming increasingly important in the Florida economy and offers potential for added amount of feed and forage.

The study, begun at Quincy and completed at Gainesville, Florida, covered the period 1975-1978. In 1975, bionomics and behavior of the sorghum midge pertinent to controlling the pest were studied. Effects of sorghum planting dates and insecticides on midge infestation and sorghum yield were determined in 1976. In 1977, data to determine the infestation level of 52 and 19 grain and silage sorghum hybrids, respectively, were gathered from Marianna, Live Oak, Ona, Immokalee, and Gainesville; and in 1978, effects of no-tillage method of production and nitrogen fertilizer levels on sorghum flowering, midge infestation, and sorghum yield following winter cropping of rye and lupin were studied.

The studies on the bionomics and behavior of the sorghum midge included: (1) manner of dispersal and time at which midges invade a sorghum field, (2) infestation pattern of the midge for oviposition in the top, middle, and bottom parts of the sorghum heads (3) temporal

emergence pattern of adult midges from sorghum heads, (4) stages of the sorghum head most susceptible to the midge after exertion from the boot, and (5) dynamics of the sorghum midge population in sorghum. Summary of the results and their practical significance follow.

Results of the study on manner of midge dispersal and time of sorghum field invasion showed that dispersal of the midge depended on the prevailing wind. Midges were trapped on the leeward side of the sorghum field but not on the windward side. Time of field invasion was related to the time of sorghum head emergence from the boots. No midges were detected in the field before sorghum started to put on heads.

These results are considered to be significant and could be used to manipulate populations of the midge in sorghum by considering the following points: (1) select a sorghum field site on the windward side of midge infestation source, and (2) plant a border crop around a sorghum field to trap and arrest invading midges.

Regarding the infestation pattern of the head for oviposition, results of the study indicated no significant preference of the midge for a particular position on the head for oviposition. The sorghum midge was found to be non-selective and to uniformly infest sorghum heads.

Significance of these results is that in planning to control the midge in sorghum, the whole sorghum head should be considered. If the control tactic involves spraying, then the entire head should be fully covered.

Results of the study on sorghum midge emergence showed that midge emergence from the sorghum heads was higher in the morning hours (4:00 a.m. to 11:00 a.m.) than in the afternoon hours (Figure 6).

Practically, these results could be used for (1) timing of field sampling and scouting for sorghum midges and (2) planning a timely spray schedule to control the midge.

Field sampling and scouting scheduled for morning hours can provide a reliable estimation of the midge population because midges (which spend most of their lifetime concealed in the sorghum spikelets) are visibly active on the sorghum heads and can be easily counted. Afternoon sampling and scouting would be less reliable because scarcely any midges move on the sorghum heads at that time. Spraying timed to operate between 4:00 and 11:00 a.m. can also achieve maximum midge mortality. An afternoon spraying would be less economical for the same reason above.

Results of the study on susceptibility of sorghum to midge attack indicated that infestation of the heads began 2 days after head emergence from the boot and continued for ca 10 days. Heaviest infestation occurred between Days 4 and 7 after head emergence.

These results suggest the need for an immediate protection of the sorghum heads after emergence. Insecticide could be applied then and continued at 3-4 day intervals up to Day 10 to assure presence of insecticide residues on the sorghum heads against ovipositing midges.

Results of the study on the dynamics of the sorghum midge population in sorghum showed that midge population was small early in the growing season (June/July), but the population increased in August/September. Factors favoring increase in the midge population were found to include presence of continuously flowering sorghum and steady rise in percentage of female midges in the course of the growing season. Female midges constituted 32.7% of the total number of midges

on 15 July, but the percentage increased to 62.0% at the end of the growing season—15 September.

These results are of practical importance because they appear to suggest that production practices aimed at reducing prolonged and uneven blooming of sorghum in the field should be adopted if midge population in sorghum fields is to be retarded. These practices among others could include the use of pure seed of a uniform blooming strain, preparation of a good seedbed for a uniform crop stand, and spacing plants to avoid uneven tillering.

Results of the study on date of planting showed that sorghum planted on 15 and 31 March sustained 0.8 and 7.8 grain loss, respectively. This was less than the loss sustained in sorghum planted in July (94.0%). Yield from the sorghum planted in March ranged from 11,076 to 15,992 kg/ha much higher than the yield from later plantings which ranged from 1,202 to 2,353 kg/ha. Early planting of grain sorghum, therefore, is the surest practical way to escape midge damage and produce high yield.

Regarding the insecticide study, evaluation of diazinon, methyl parathion, carbaryl, dimilin, FMC 33297, (each at two concentrations—high and low), indicated no significant difference in their effects on yield or midge populations at both rates, although yield in the diazinon treated plots was highest (7,009 kg/ha at the high rate of 0.3 kg ai/ha, and 6,645 kg/ha at the low rate of 0.1 kg ai/ha). Diazinon is currently recommended for midge control in Florida sorghum (Anonymous, 1975b). These results therefore not only verified the recommendation but confirmed diazinon's potency for midge control. However, the other chemicals tested have potential for midge control also.

The data gathered to determine susceptibility of grain and silage sorghums showed that the grain sorghum hybrids Young (Surgro) (FMC) Early Oro, ACCO D-2912(ex-0912), and DeKalb BR-64 (with 1.4%, 1.3%, and 1.2% grain loss, respectively) appeared consistently susceptible throughout Florida. Pioneer 8311, TE(Golden Acres) Hondo, DeKalb D-46, and Ring Around 808GB, (with 0.7% grain loss each), appeared less susceptible. The majority of the grain sorghum hybrids were mid-range in their response to the sorghum midge.

These results, preliminary as they are, could be used as (1) background data on which to base further research for more information and (2) initial guidelines for release of hybrids that could prevent the increase of a potentially devastating sorghum midge population.

Comparison of the grain with the silage sorghums indicated that the silages were more susceptible to the midge than the grains. Number of midges/head (5.0 midges vs 0.9 midges) and percent grain loss (15.7% vs 1.0%) were higher for the silage than for the grain sorghum hybrids.

Since the silage sorghum hybrids appear to be favorable hosts for the midge, but grown for livestock fodder, harvest before they begin to bloom may be a practical way to reduce sorghum midge population in an area.

Results of the study on no-tillage production of grain sorghum indicated that lupin mulch and lupin stubble no-tillage treatments significantly reduced the number of days for mid-bloom to 64.5±1.5 and 65.3±1.6 days, respectively. Percent grain loss was reduced to 4.3±0.7% and 4.8±0.9%, and grain yield increased to 3.5 and 4.1 metric tons/ha in these culture systems.

Days to mid-bloom and percent grain loss in the rye and conventional tillages were comparatively higher.

Effect of the nitrogen fertilizer on number of days to mid-bloom, grain loss, and sorghum yield showed that as the nitrogen fertilizer level increased from 0 to 224 kg/ha, days to mid-bloom decreased and percent grain loss also decreased. Total yield increased with each added increment of nitrogen fertilizer (Figure 13).

All tillage-nitrogen interactions indicated responses more favorable to sorghum planted in the lupin no-tillage treatments than to sorghum planted in the conventional or rye no-tillage treatments. Whereas sorghum in the rye no-tillage (mulch or stubble) treatments consistently took more days to mid-bloom at each added increment of nitrogen, sorghum in the lupin no-tillage (mulch or stubble) treatments took less number of days (Figure 14), with percent grain loss generally lower than in the former tillage treatments (Figure 15). However, as the amount of nitrogen level increased to 56 kg/ha and then to 224 kg/ha, percent grain loss in all tillages first decreased to within 2.5-7.5%, and then the differences among tillages narrowed strikingly (Figure 15).

Yield increased in all tillages as the level of the nitrogen fertilizer increased. But sorghum planted in the lupin mulch no-tillage ranked the best (Figure 16).

In summary, no-tillage production of grain sorghum was better when sorghum was planted after lupin in either mulch or stubble than when it followed rye or conventional tillages. The sorghum flowered early and escaped midge damage better than in the latter tillages.

Figure 17. Blooming sorghum head under sorghum midge attack. Quincy, Florida. 1976.

Figure 13. Female of the sorghum midge, Contarinia sorghicola (Coquillett), ovipositing in a sorghum spikelet.

Figure 19. Male (A) and female (B) of the sorghum midge, Contarinia sorghicola (Coquillett). Quincy, Florida. 1976.

A
A
B
B

Figure 20. Sorghum midge puparium. Quincy, Florida. 1976.

Figure 21. Female of the sorghum midge parasite, Aprostocetus diplosidis Crawford.

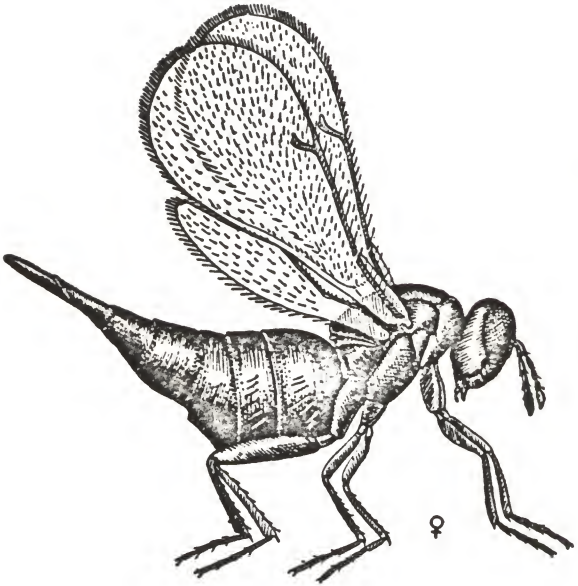
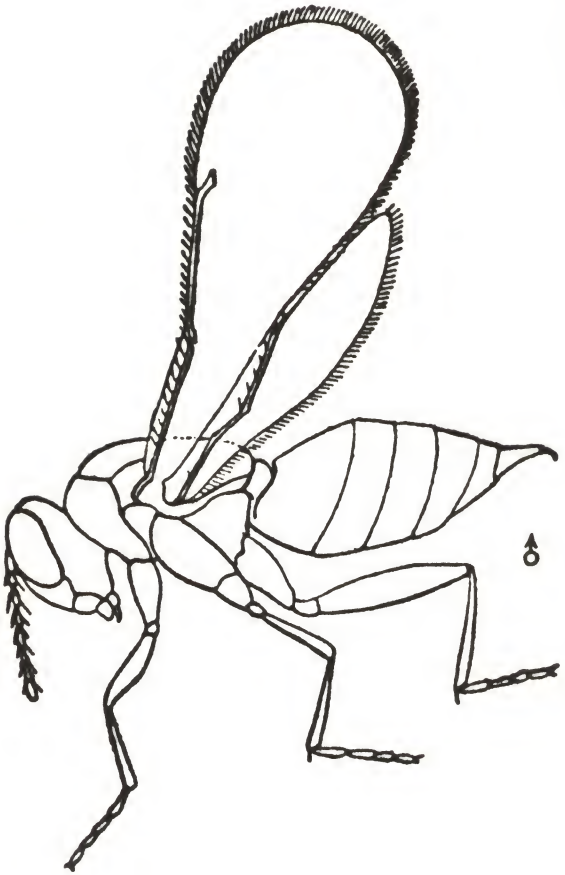


Figure 22. Male of the sorghum midge parasite, Aprostocetus diplosidis Crawford.



APPENDIX

Appendix Table 1. Head structure and seed characteristics of 52 grain sorghum hybrids grown in Florida in 1977.

Brand	Hybrid	Head[1] structure	Seed Color[2]	
			Pericarp	Endosperm
Funks	G-399	SO	R	WE
Young (Surgro) (FMC)	Early Oro	O	RBr	YE
ACCO	D-2912 (ex-0912)	SO	R	YE
Funks	G-589	C	R	YE
Young (Surgro) (FMC)	Oro-DR	SC	R	YE
Growers	ML-135	SO	R	YE
DeKalb	BR-64	O	Br	WE
DeKalb	F-67	O	R	HYE
ACCO	BR Y-93 (X-8418)	O	Br	YE
Funks	G-522	so	R	HYE
Funks	G-516 BR	O	Br	HYE
McCurdy	M51 YG	SO	R	YE
Funks	G-662	O	R	HYE
McCurdy	Birds-off 91	O	RBr	WE
ACCO	DR 1085	SO	R	YE
Ring Around (XL)	RA 811 GB	SC	R	HYE
Pioneer	8272	SC	R	WE
Funks	HW4060	O	Br	WE
Northrup King	Savanna 5 (3101A)	C	RBr	WE
DeKalb	D-55	C	R	WE
TE (Golden Acres)	Y-101-R	SC	R	YE
Growers	Exp-73022	SO	R	YE
Funks	HW 2163	SC	R	HYE
Growers	GSA 1334 BR	O	Br	YE
McCurdy	Birds-off 81	O	Br	HYE
Northrup King	Savanna 3	O	RBr	YE
Pioneer	8225	SC	RBr	WE
ACCO	1029A	SO	R	YE
Funks	G-722DR	C	R	HYE
ACCO	R1090	O	R	YE
Ring Around (XL)	RA747	C	R	WE
Funks	G-623 GBR	SO	R	HYE
TE (Golden Acres)	Total-R	SO	R	YE
Northrup King	NK 2778	SO	R	YE
DeKalb	E 59+	SO	R	HYE
Young (Surgro) (FMC)	Oro	SO	R	YE
TE (Golden Acres)	Birds-a-boo 2	O	Br	WE
DeKalb	BR 65+	SO	RBr	WE
DeKalb	D-60	SO	R	WE
Pioneer	8454	SO	R	YE
Growers	Exp-75005	O	Br	YE

Appendix Table 1 - continued

Brand	Hybrid	Head[1] structure	Seed Color[2]	
			Pericarp	Endosperm
Funks	BR-79	O	Br	WE
Ring Around (XL)	RA Bird Go 68	O	Br	YE
Young (Surgro) (FMC)	Oro-T	SC	R	YE
Ring Around (XL)	RA 808GB	SO	R	YE
Young (Surgro) (FMC)	Oro-Y	O	Y	YE
TE (Golden Acres)	Hondo	C	R	WE
Pioneer	B-815 BR	SC	Br	HYE
Pioneer	8311	SC	R	YE
Funks	G-642 GBR	O	Y	YE
Northrup King	NK 2779	O	R	YE
DeKalb	D-46	SC	R	WE

[1] Head structure: SC - semi-compact, O = open, SO = semi-open, C = compact.

[2] Seed color: Pericarp: R = red, RBr = red-brown, Br = brown, Y = yellow. Endosperm: WE = white endosperm, YE = yellow endosperm, HYE = half yellow endosperm.

Appendix Table 2. Grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett), in 52 grain sorghum hybrids in three Florida locations—Marianna, Live Oak, and Gainesville, 1977.

Brand	Hybrid	% grain loss per head at Marianna	Live Oak	Gainesville
Funks	G-399	1.1 a	1.4 ab	1.8 ab[1]
Young (Surgro) (FMC)	Early Oro	1.3 a	0.7 b	2.2 a
ACCO	D-2912(ex-0912)	1.4 a	0.7 b	1.9 ab
Funks	G-589	1.8 a	1.5 ab	0.7 d
Young (Surgro) (FMC)	Oro-DR	1.7 a	1.4 ab	0.7 d
Growers	ML-135	1.6 a	1.4 ab	0.8 cd
DeKalb	BR-64	1.5 a	0.7 b	1.5 abc
DeKalb	F-67	1.5 a	1.5 ab	0.7 d
ACCO	BR Y-93 (x-8418)	1.1 a	1.4 ab	1.1 bcd
Funks	G-522	1.2 a	1.3 ab	1.1 bcd
Funks	G-516 BR	1.8 a	0.7 b	1.1 bcd
McCurdy	M51 YG	1.1 a	0.7 b	1.8 ab
Funks	G-622	1.3 a	0.7 b	1.5 abc
McCurdy	Birds-off 91	1.2 a	1.5 ab	0.7 d
ACCO	DR 1085	1.3 a	0.9 ab	1.1 bcd
Ring Around (XL)	RA 811 GB	0.7 a	1.4 ab	1.1 bcd
Pioneer	8272	1.3 a	1.2 ab	0.7 d
Funks	HW 4060	0.7 a	1.8 a	0.7 d
Northrup King	Savanna 5 (3101A)	1.7 a	0.7 a	0.7 d
DeKalb	D-55	1.3 a	1.1 ab	0.7 d
TE (Golden Acres)	Y-101-R	1.6 a	0.7 b	0.7 d
Growers	Exp-73022	1.6 a	0.7 b	0.7 d
Funks	HW 2163	0.7 a	1.5 ab	0.7 d
Growers	GSA 1334 BR	0.7 a	1.5 ab	0.7 d
McCurdy	Birds-off 81	0.7 a	1.4 ab	0.7 d
Northrup King	Savanna 3	0.7 a	1.4 ab	0.7 d
Pioneer	8225	0.7 a	1.4 ab	0.7 d
ACCO	1029A	1.3 a	0.7 b	0.7 d
Funks	G-722DR	1.3 a	0.7 b	0.7 d
ACCO	R1090	1.4 a	0.7 b	0.7 d

Appendix Table 2 - continued

Brand	Hybrid	% grain loss per head at Marianna	Live Oak	Gainesville
Ring Around (XL)	RA 747	1.3 a	0.7 b	0.7 d
Funks	G-623 GBR	0.7 a	0.7 b	0.7 d
TE (Golden Acres)	Total-R	0.7 a	1.2 ab	0.7 d
Northrup King	NK 2778	1.2 a	0.7 b	0.7 d
DeKalb	E 59+	1.2 a	0.7 b	0.7 d
Young (Surgro) (FMC)	Oro	1.1 a	0.7 b	0.7 d
TE (Golden Acres)	Bird-a-boo 2	1.1 a	0.7 b	0.7 d
DeKalb	BR 65+	1.1 a	0.7 b	0.7 d
Pioneer	8454	0.7 a	1.1 ab	0.7 d
Growers	Exp-75005	1.1 a	0.7 b	0.7 d
Funks	BR-79	0.7 a	0.7 b	0.7 d
Ring Around (XL)	RA Bird Go 68	0.7 a	0.7 b	0.7 d
Young (Surgro) (FMC)	Oro-T	0.7 a	0.7 b	0.7 d
Ring Around (XL)	RA 808 GB	0.7 a	0.7 b	0.7 d
Young (Surgro) (FMC)	Oro-Y	0.7 a	0.7 b	0.7 d
TE (Golden Acres)	Hondo	0.7 a	0.7 b	0.7 d
Pioneer	B-815 BR	0.7 a	0.7 b	0.7 d
Pioneer	8311	0.7 a	0.7 b	0.7 d
Funks	G-642 GBR	0.7 a	0.7 b	0.7 d
Northrup King	NK 2779	0.7 a	0.7 b	0.7 d
DeKalb	D-46	0.7 a	0.7 b	0.7 d
Location average		1.1	1.0	0.9

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Appendix Table 3. Numbers of the sorghum midge, Contarinia sorghicola (Coquillett), emerged from sorghum heads of 20 grain sorghum hybrids in three Florida locations—Marianna, Live Oak, and Gainesville, 1977.

Brand	Hybrid	Avg. number of midges per head at Marianna	Live Oak	Gainesville
McCurdy	M 51-YG	1.3 ab	0.9 a	2.2 a[1]
ACCO	D-2912(ex-0912)	1.6 ab	0.7 a	1.6 ab
DeKalb	BR-64	1.8 ab	0.8 a	1.1 bc
Pioneer	8454	1.9 a	0.8 a	0.8 c
Young (Surgro) (FMC)	Early Oro	0.8 ab	1.0 a	1.3 bc
Northrup King	Savanna 3	0.7 b	1.0 a	1.1 bc
McCurdy	Birds-off 81	1.4 ab	0.7 a	0.7 c
Funks	G-522	1.1 ab	0.8 a	0.8 c
ACCO	R-1090	0.7 b	0.8 a	1.2 bc
Ring Around (XL)	RA 747	0.7 b	1.0 a	0.8 c
Funks	HW 4060	0.7 b	1.1 a	0.7 c
Northrup King	Savanna 5(x-3101A)	1.0 ab	0.7 a	0.7 c
Ring Around (XL)	RA-811GB	1.0 ab	0.7 a	0.7 c
Funks	G-399	0.8 ab	0.7 a	0.7 c
Pioneer	8311	0.8 ab	0.8 a	0.7 c
TE (Golden Acres)	Hondo	1.0 ab	0.7 a	0.7 c
DeKalb	D-46	0.9 ab	0.7 a	0.7 c
TE (Golden Acres)	Total-R	0.9 ab	0.7 a	0.7 c
Growers	ML-135	0.7 b	0.8 a	0.7 c
Ring Around (XL)	RA 808 GB	0.7 b	0.7 a	0.7 c
Location averages		1.0	0.8	0.9

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Appendix Table 4. Numbers and percent grain loss caused by the sorghum midge, Contarinia sorghicola (Coquillett) in silage sorghum hybrids in three Florida locations—Gainesville, Ona, and Immokalee, 1977.

Brand	Hybrid	Locations					
		Gainesville		Ona		Immokalee	
		No. of midges per head	Avg. % grain loss per head	No. of midges per head	Avg. % grain loss per head	No. of midges per head	Avg. % grain loss per head
Northrup King	367	9.8 a[1]	14.8 cde	----	----	---	----
ACCO	FS-401R	6.2 bcde	13.1 e	10.0 ab	13.5 a	5.8 ab	13.4 ab
Funks	102F	4.2 cdef	17.0 cde	10.7 a	14.1 a	6.3 ab	13.4 ab
ACCO	FS-401R	8.8 ab	14.9 cde	2.4 cde	18.0 a	9.1 a	20.2 ab
McCurdy	F-75	6.0 bcde	14.8 cde	6.5 abcd	17.0 a	5.3 ab	11.7 ab
DeKalb	FS-24+	6.1 bcde	14.9 cde	6.3 abcd	14.8 a	4.8 ab	14.4 ab
Funks	G-605-S	5.6 cdef	25.3 a	6.2 abcd	13.2 a	6.0 ab	17.7 ab
Taylor Evans	Silomaker	6.1 bcde	15.6 cde	5.2 bcde	14.8 a	5.5 ab	10.0 b
Ring Around	Silofill 35	6.4 bcd	15.6 cde	4.3 cde	13.2 a	---	----
Pioneer	947	5.0 cdef	18.4 b	4.5 cde	16.7 a	5.7 ab	11.7 ab
Growers	30F	7.1 abc	21.5 b	1.9 cde	16.9 a	6.3 ab	14.6 ab
Funks	G-103-S	5.2 cdef	13.9 de	5.3 bcde	16.9 a	1.5 b	25.7 a
Northrop King	Silomilo	2.6 f	14.0 cde	7.0 abc	14.4 a	2.6 b	17.4 ab
DeKalb	FS-25+	3.5 def	16.3 cde	3.8 cde	14.6 a	4.4 ab	25.8 a
Pioneer	923	4.2 cdef	13.3 e	2.0 cde	13.1 a	5.5 ab	18.4 ab
Northrup King	300	3.5 def	15.6 cde	----	----	---	----
Taylor Evans	TDN	4.7 cdef	17.7 cd	0.7 e	13.1 a	2.9 ab	11.0 b
McNair	Energy Plus	---	----	0.8 e	14.9 a	4.9 ab	18.4 ab
Pioneer	942	3.2 ef	15.4 ef	1.3 de	15.4 a	0.7 b	10.0 b
Location averages		5.4	16.2	4.7	15.0	4.8	15.9

[1] Column averages followed by the same letter are not significantly different at 5% Duncan's multiple range test.

Appendix Table 5. Percent parasitization of the sorghum midge, Contarinia sorghicola (Coquillett), by the parasite Aprostocetus diplosidis Crawford on each of 20 grain sorghum hybrids in three Florida locations—Marianna, Gainesville, and Live Oak, 1977.

Brand	Hybrid	Locations and sampling dates				
		Marianna		Gainesville		Live Oak
		22 July	11 Oct	24 June	1 Oct.	28 July
		% parasitism				
DeKalb	BR-64	0.0	55.9*	0.0	82.0	0.0
Funk	G-522	0.0	53.4	0.0	15.9	50.0
ACCO	R-1090	0.0	38.8	0.0	14.3	50.0
Young(Surgro)(FMC)	Early Oro	50.0	12.7	0.0	0.0	0.0
NK	Savanna 3	0.0	25.5	0.0	8.2	33.3
McCurdy	Birds-off 81	0.0	12.3	0.0	36.1	0.0
Ring Around	RA 808GB	0.0	41.6	0.0	28.6	10.0
TE (Golden Acres)	Hondo	0.0	80.7	0.0	0.0	0.0
McCurdy	M 51-YG	0.0	47.5	0.0	0.0	0.0
TE (Golden Acres)	Total-R	0.0	73.4	0.0	27.3	0.0
Pioneer	8311	50.0	54.6	0.0	25.0	0.0
Funk	G-399	0.0	83.3	0.0	0.0	0.0
Growers	ML-135	0.0	62.9	0.0	17.7	0.0
Ring Around	RA-811GB	0.0	41.3	0.0	6.3	0.0
ACCO	D-2912(ex-0912)	0.0	88.4	0.0	0.0	0.0
Pioneer	8454	0.0	49.4	0.0	0.0	0.0
DeKalb	D-46	0.0	10.0	0.0	3.3	0.0
Ring Around(XL)	RA 747	50.0	15.0	0.0	15.8	40.0
Funk	HW 4060	0.0	25.0	0.0	60.0	40.0
NK	Savanna 5	0.0	8.8	0.0	0.0	0.0
Average		7.5	43.9	0.0	14.3	11.2

* Sorghum from which data were collected were grown in nursery seedbeds.

Appendix Table 6. Percent parasitization of the sorghum midge, Contarinia sorghicola (Coquillett), by the parasite Aprostocetus diplosidis Crawford on each of 19 Silage sorghum hybrids in three Florida locations—Gainesville, Ona, and Immokalee, 1977.

Brand	Hybrid	Locations and sampling dates		
		Gainesville 15 Oct.	Ona 30 Aug.	Immokalee 30 Aug.
		% parasitism		
ACCO	FS-531R	0.0	3.6	22.2
ACCO	FS-401R	3.5	25.3	27.4
DeKalb	FS-24+	17.2	0.0	10.4
DeKalb	FS-25+	16.7	1.3	37.2
Funk	102F	2.8	2.0	3.5
Funk	G-103-S	12.9	0.0	53.9
Funk	G-605-S	15.4	5.3	29.9
Growers	30F	7.7	31.8	17.2
Northrup King	Silomilo	0.0	0.0	0.0
McCurdy	F-75	5.5	0.5	0.0
McNair	Energy Plus	---	38.5	38.8
Pioneer	923	6.5	0.0	29.0
Pioneer	942	56.6	40.0	100.0
Pioneer	947	40.2	46.7	3.2
Taylor Evans	Silomaker	23.6	41.6	15.7
Taylor Evans	TDN	12.6	0.0	27.6
Ring Around	Silofill 35	17.2	0.0	----
Northrup King	300	15.8	---	----
Northrup King	367	0.0	---	----
Average		14.1	13.9	26.0

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BIOGRAPHICAL SKETCH

Rubena Lumaya Wani was born on 1 December 1940 at Yei, Sudan. He received his college education in Agriculture from the University of Khartoum, Sudan, where in March 1966, he obtained the degree of Bachelor of Science. After graduation, he accepted the position of an Assistant Research Scientist in the Agricultural Research Corporation, Ministry of Agriculture, Sudan. He returned to the University of Khartoum in July 1966 to pursue studies leading to the degree of Master of Science. Majoring in entomology, he was graduated in March 1969.

In 1970, Wani accepted the position of a Research Scientist in Entomology with the Agricultural Research Corporation, Entomology Section, Sudan. Two years later he was promoted to Head of Cotton Research Station, Kadugli, Sudan—a position he held from 1972 to 1974. In 1973, he represented his country in a two-month study course held at Gainesville, Florida, on radiation techniques and their application to insect pests. In September 1974, he was offered a scholarship by the Government of the Sudan to pursue studies in the USA leading to the degree of Doctor of Philosophy. Currently, he is enrolled in the Department of Entomology and Nematology for the doctoral degree.

Wani is married to the former Rakele Keji Alfonse. They are parents of three children—two boys (Diab, 5, and Lugela, 1), and a lovely two-year-old girl, Mimi.

Wani is a member of the Agricultural and Entomological Society of the Sudan.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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